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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARD CONFERENCE PROCEEDINGS 532

Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques

(Les Accidents d'Aéronefs: les Tendances en Techniques d'Investigation Médicale)

Papers presented at the Aerospace Medical Panel Symposium held in Cesme, Turkey, 27th April—1st May 1992.

NORTH ATLANTIC TREATY ORGANIZATION

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North Atlantic Treaty Organization

Organisation du Traité de l'Atlantique Nord

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- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;
- Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
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Preface

The loss of fiscal, material, and personnel resources and the degradation of mission readiness as a result of aircraft accidents are important areas of concern for NATO nations. Tremendous technological advances in human operated aviation systems have made it possible to significantly expand the operational role of NATO military aviation and allowed persons operating those systems to accomplish increasingly more complex missions. At the same time these advances have tremendously complicated human tasks and increased aircrew workload to the point of overloading human capabilities. Also, the cost of producing these sophisticated aviation systems and of the training of humans to operate them have become exponentially more expensive, concurrently drastically increasing the cost of losses due to aviation accidents.

As the complexity of aviation systems has increased, so has the task of investigating aircraft accidents. New technologies have had to be applied in order to determine the causes of accidents and new techniques developed in order to assess such things as the mechanisms of injuries sustained in accidents. Human factors continue to cause the vast majority of aviation accidents, and the accurate depiction of accidental injuries and fatalities continues to be a challenge to epidemiologists as they endeavor to isolate causative factors of both accidents and injuries, so that remedial measures can be taken to reduce accident rates and morbidity and mortality.

The AGARD Executive, the Aerospace Medical Panel, and its Biodynamics and Human Factors Committees decided upon this Symposium as an efficient means of pulling together information on how NATO nations are addressing the tasks of investigating the aerospace medical aspects of aircraft accidents. These proceedings are the product of that effort; a compilation of papers detailing proven investigative techniques, analyzing accident information from vast databases, describing successes in prevention, and proposing new research areas attacking yet to be solved problems.

Papers cover the following topics:

- human factor causes of accidents;
- occupant injury investigation (including simulation);
- test devices for dynamic response;
- fixed and rotary wing aircraft accident data;
- spatial disorientation;
- injury and accident prevention;
- post crash fire, toxicology, and forensic pathology;
- crew error prevention;
- crew risk factors

Préface

La perte de moyens matériels, personnels et fiscaux et la dégradation de la disponibilité opérationnelle qui résultent des accidents d'avion sont des questions préoccupantes pour les pays membres de l'OTAN. Les progrès technologiques énormes réalisés dans le domaine des systèmes d'aviation pilotés ont permis une extension considérable du rôle opérationnel de l'aviation militaire de l'OTAN, en autorisant les personnes qui pilotent ces systèmes à accomplir des missions de plus en plus complexes.

En même temps, ces progrès ont rendu très compliqués les tâches de l'opérateur et augmenté la charge de travail des équipages au point de saturation des capacités humaines. De plus, les coûts de fabrication de ces systèmes d'aviation sophistiqués et le coût de la formation des opérateurs ont augmenté de façon exponentielle, ce qui a eu pour effet d'augmenter radicalement le coût des pertes suite aux accidents d'avion.

La complexité croissante des systèmes d'aviation a rendu plus complexe la tâche des enquêteurs sur les accidents d'avion. Il a fallu mettre en oeuvre de nouvelles technologies afin de déterminer les causes des sinistres et développer de nouvelles techniques, par exemple pour l'évaluation des méchanismes des blessures reçues. Le facteur humain reste la cause de la grande majorité des accidents d'avion et la représentation fidèle des blessures accidentelles et des accidents mortels continue à être un défi pour les épidémiologues qui tachent d'isoler les facteurs causatifs des accidents et des blessures, afin de rendre possible la mise en oeuvre de mesures correctives qui réduiront le nombre, la morbidité et la mortalité des accidents.

Le Panel AGARD de Médecine Aérospatiale, son Administrateur et les Comités des Facteurs Humains et de la Biodynamique du Panel ont décidé que ce Symposium était le moyen le plus efficace pour rassembler des informations sur l'approche adoptée par les membres de l'OTAN sur le problème de l'investigation des aspects médicaux des accidents d'avion. Ce compte rendu représente
le produit final de tous ces efforts. Il s'agit d'un recueil de présentations qui décrivent les techniques d'investigation qui ont fait leurs preuves, qui analysent les données d'accident fournies par des bases de données importantes, qui énumèrent les succès obtenus dans le domaine de la prévention et qui proposent de nouveaux domaines de recherche qui permettront d'aborder les problèmes qui restent à résoudre.

Les communications couvrent les sujets suivants:

- le facteur humain dans les accidents
- l'investigation des blessures reçues par les occupants (y compris la simulation)
- les installations d'essai de la réponse dynamique
- les données d'accident sur les aéronefs à voilure fixe et à voilure tournante
- la désorientation spatiale
- la prévention des accidents et des blessures
- les incendies suite aux accidents, la toxicologie et la pathologie légale
- la prévention des erreurs de la part de l'équipage
- les facteurs de risque pour l'équipage

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1. INTRODUCTION

The Aerospace Medical Panel Symposium on "Aircraft Accidents: Trends In Aerospace Medical Investigation Techniques" was held at the Altin Yunus Hotel, Cesme, Turkey, from April 27 to May 1, 1992. Authors from 11 NATO countries and 1 non-NATO country presented 58 papers.

2. THEME

The theme of the symposium was recent trends in aerospace medical investigation techniques in aircraft accident reconstruction. Since the early commencement of aviation, accidents have occurred for a variety of reasons in both fixed- and rotary-wing aircraft. Progress in technology has increased significantly the reliability of airframe, avionics and propulsion systems. However, at the same time advanced techniques in aviation and weapon systems have exacerbated greatly the physiological and cognitive demands on aircrew. The result is that aircraft accidents due to material causes have diminished progressively while the percentage of human factor-caused accidents has not. The formal investigation of an aircraft accident by engineering and human factors specialists is essential not only to identify the cause, but also to make recommendations to improve the man-machine interface and reduce human error accidents.

3. PURPOSE AND SCOPE

The purpose of the symposium was to discuss recent trends in human factors-related accidents and current techniques utilized to elucidate accident and injury cause factors during the investigation and reconstruction process.

The scope of the symposium was extremely broad. Participants included operational experts, pilots, psychologists, human factors specialists, flight surgeons, air safety specialists, physiologists and engineers from a myriad of military and civilian organizations in 12 countries. Topics included techniques of human factors accident investigation, reviews of accident cause factors, injury investigation techniques, simulation techniques, human surrogate design, mathematical modelling, spatial disorientation, forensic techniques and accident prevention.

4. SYMPOSIUM PROGRAM

The symposium comprised 11 sessions each emphasizing different aspects of aircraft accident cause factors, investigation and reconstruction techniques, and methods of accident prevention. The large number of sessions reflects the diversity and complexity of the subject area and the high level of interest in the symposium.

The first session, "Investigation: Human Factors," covered methods in performing human factors investigations of aircraft accidents.

The second session, "Investigation: Occupant Injury and Simulation," discussed occupant injury in crashes emphasizing mechanisms of injury and methods of simulating occupant response to crash forces.

The third session, "Investigation: Test Devices for Dynamic Response," comprised a number of papers describing the use of manikins for crash impact simulation and new efforts to improve manikin biofidelity.

The fourth session, "Accident Data Analysis: Fixed-Wing Accidents," concentrated on human factor causes of fixed-wing accidents in various NATO air forces.

The fifth session, "Accident Data Analysis: Spatial Disorientation," included papers that discussed spatial disorientation and illusions as an accident cause factor. Means of establishing spatial disorientation as a causative factor, as well as means of preventing spatial disorientation also were discussed. Also presented was a paper on performance effects of moderate levels of blood alcohol.

The sixth session, "Accident Data Analysis: Rotary-Wing Accidents," was focused on general aspects of the epidemiology of helicopter crashes. Several papers were devoted to ditching accidents while two others focused on crashworthiness aspects of helicopter and life support equipment design.

The seventh session, "Rotary-Wing Injury and Accident Prevention," was largely a continuation of the previous session concentrating on accident and injury prevention in rotary-wing operations.

The eighth session, "Accident Pathology: Fire and Toxicology," discussed various aspects of fire safety, toxicology, and the toxicological investigation of aircraft accidents.

The ninth session, "Accident Pathology: Forensic Studies," continued the theme of the previous session, but concentrated on gross and histologic postmortem findings in the investigation of aircraft accidents.

The tenth session, "Accident Prevention: Reducing Crew Error," covered a range of topics relating to methods to prevent human error aviation mishaps.

The final session, "Accident Prevention: Technical Solutions and Risk Factors," included a diversity of papers dealing with known and postulated risk factors predisposing to human error and methods for detecting and limiting the deleterious effects of these factors.

5. TECHNICAL EVALUATION

The medical investigation of aircraft accidents is an enormously complex task requiring the integration of expertise from numerous related fields including medicine, psychology, engineering, and the basic sciences. For the purposes of this symposium, presentations were divided into two major areas of concentration--human factors considerations in accident causation and biodynamic and toxicological considerations in injury causation. The human factors portion of an aircraft accident investigation attempts to establish the chain of events that led to the accident and the roles human actions played in these events. The main emphasis being to determine why the accident occurred and, more importantly, what can be done to prevent similar accidents. Properly conducted, such an investigation encompasses considerations of aircraft design; operational procedures; aircrew, ground crew, and management training; and physiological and psychological factors influencing personnel involved in the chain of events leading to the accident.

The injury investigation portion of an accident investigation attempts to establish the cause or mechanism of each injury sustained by an occupant of the accident aircraft. A clear understanding of injury mechanisms is required to devise effective means of preventing or reducing injuries in future crashes. The determination of injury mechanisms requires a thorough reconstruction of the physical crash events in order to determine the sequence, magnitude, direction, and duration of crash forces. From this information, one can reconstruct the dynamic response of the aircraft, its components, and its occupants during the crash and identify injurious interactions between the occupant and his surrounding environment. Failure modes of structure including the aircraft floor, seats, and restraint systems are identified and correlated to injury. Finally, postcrash factors such as availability of escape paths and inhibition of escape by debris, fire, toxic smoke, water, or other factors are considered.

Session I

Session I of this meeting was dominantly concerned with descriptions of how different nations address the human factors investigation of flying accidents and maintain records of the investigations. The exception to this general theme was the presentation by Cetinguc that described a study in the Turkish Air Force in which pilots completed two tests, the "State Trait Personality Inventory" and the "Zung Depression Scale," in order to assess well-being, distress, anxiety, and depression. It was the contention of the author that these factors combine to generate the general concept of "morale" and he discovered, to his apparent surprise, that a group of over 300 pilots appeared to have better (in these terms) morale than a control group of nonflying air force officers. The author suggests some reasons for this (selection of individuals in the groups, professional pride, and some psychoanalytic factors) but might also have pointed out that flying is the core occupation in an air force, with all other occupations supporting it, and this focus on the pilot as the individual with a central role is likely to be reflected in his job satisfaction.

The relationship between the morale of the pilot and safety was not explored by Cetinguc, but the presentation by Rameckers provided a conceptual framework for examining such effects. Both Rameckers and Green, the symposium's lecturer, emphasized the extent to which investigations of the human factor in accident investigation have moved from addressing the events that occurred in the cockpit and the associated behavioral characteristics of the crew members, to a wider consideration of the human factors within the management and organization of the total system within which the pilots operated. The importance of this wider approach is twofold. The first advantage is that the higher within the hierarchy of a management system that a fault or unsafe procedure can be identified, the more generality rectification that fault will have. Second, the recognition that management and organization decisions and practices can affect safety means that attempts may be made to monitor "system health" in order to act as early warning of potential system failure. If the hypothesis is accepted that a management shortcoming will result in an accident only when combined--in an unlikely conjunction--with some error made by the individual, then plugging the hole at the management level is likely to make the system generally more error tolerant at the individual operator level.

Rameckers presently is trying to monitor the system health or risk state of every squadron in the Royal Netherlands Air Force. This should be regarded as a bold experiment that is breaking new ground in the area of human factors and flight safety, and its results are awaited with great interest.

The remaining three papers addressed here took a more conventional approach to the problem area, but all embodied some interesting points. Pollack gave a description of the aircraft accident investigation process in Sweden, where the inclusion of human factors specialists in the accident board has become routine. She also emphasized the importance of system factors in the accident process, but the point she made, albeit incidentally, of perhaps greatest interest concerned the nature of the investigation board. In almost all countries, the military investigates its own accidents, and the likelihood that system shortcomings will be identified with any boldness by an officer who depends on the same system for his own career advancement must be regarded as distinctly low. In Sweden, however, the investigation board is an independent authority that covers all major accidents and incidents in aviation, military as well as civilian.

It seems clear that investigation by an independent authority is a direction in which any desire or requirement for objectivity compels, but whether the vested interests in the present systems will permit this is extremely doubtful. Lack of independence of investigation might reasonably be regarded as one of those system or management factors that should be regarded as a flight safety hazard in itself.

The paper presented by David on Canadian Forces aviation highlighted, on a number of occasions, the need to spend money on tackling the human factors problem in aviation at a level commensurate with its importance. However, perhaps more interesting in this paper was the use of terminology such as "inattention," "judgement," "technique," and "carelessness" that crop up in many taxonomies of accident aetiology, but which beg definition.

A similar point could be made with regard to the paper by Levy, in which he points out that the U.S. Air Force does not use human factors specialists or psychologists in accident boards, but has had a rather unhappy experience in attempting to use flight surgeons as a substitute for them. He went on to describe the record form used in keeping U.S. Air Force life science accident data, the system used to keep the data, and the training course to which future investigators are to be subjected in order to attempt to standardize their methods of categorization. He went on to suggest that other nations should participate in the scheme in order to maximize the size of the database and establish as much commonality as possible between nations.

There can be no doubt that these are worthwhile goals that should be addressed. Other nations will doubtless wish, however, that their accident investigation experience and categorization techniques should be taken into account. Also, it should be borne in mind that although detailed record keeping is surely important, it is not a substitute for thought and insight in the initial investigation.

Overall, this session produced some thought provoking presentations, some interesting contrasts, and one or two good ideas for new procedures in human factors and air safety for the future.

Session II

The papers in this session were devoted to the investigation of occupant injury and to computer simulation of occupant response to impact. Four papers dealt with some of the findings from the investigation of the accident to the Boeing 737-400 that crashed on the M1 motorway at Kegworth in the United Kingdom in January 1989. The remaining papers dealt with mathematical modeling of occupant response to impact.

Carter's paper (number 10) presented findings that dealt with the structures investigation of the Boeing 737-400 accident and, in particular, with the investigation of the failures of the seats and aircraft floor and the overhead bins. The work indicated that it was the failure of the floor that precipitated the failure of the seats. The overhead bin failures were shown to be due to the failure of the attachment of the diagonal tie to the top surface of the bin followed by sequential failure of the remainder of the attachments. The loads on impact were estimated by the use of the hybrid computer program KRASH, and this indicated that the impact pulse was considerably outside the design limits of the bins. This impact pulse subsequently was used as the input in studies on the occupant response to impact. The author concluded, *inter alia*, that it was important to set realistic crashworthiness standards that were applicable to all items of cabin structure and not just seats in isolation.

Paper 11 (Haidar and Rock) dealt with the occupant simulation of the response to impact using the computer program MADYMO and input impact data derived from the results of the KRASH modeling. The authors analyzed occupant response and compared this with clinical injury data. The authors also looked at the effect of adopting different preimpact positions in the seat. They concluded that a brace position with the head against the back of the seat in front and with the lower legs angled back behind the knees offered the best protection.

Paper 12 (Rowles, Wallace, and Anton) considered the question of whether injury severity scoring (ISS) could provide additional useful information for crash investigators. ISS data correlated well with structural damage to the aircraft. Variations in the ISS were useful markers for other injury mechanisms such as being struck by overhead items or interactions with other passengers. The authors concluded that both abbreviated injury scale (AIS) and ISS coding are valuable techniques in analyzing passenger injury data.

Paper 13 (Powles, Anton, and Wallace) dealt with anomalies in patterns of femoral fracture in the Kegworth accident. The conventional explanation for femoral fracture on $-G_z$ impact is axial loading. Data from the Kegworth accident indicated that femoral fractures occurred in the absence of knee injury. There was a statistically significant association between sitting in the center of a row and sustaining a femoral fracture. The authors concluded femoral bending rather than axial loading was the mechanism of fracture. This appeared to be due to a complex interaction between the seat occupant and his seat.

Paper 14 (Nieboer and Wismans) dealt with the use of computer simulation of impact. The paper concentrated on the application of MADYMO in crash simulation research and used as examples astronaut escape, a three dimensional simulation of the Kegworth accident, and a simulation of a 16G dynamic seat test.

Paper 15 (Walker, Sturt and Boag-Izatt) described the use of OASIS DYNA3D as a computer program for use simulating occupant response to impact. DYNA3D is a three-dimensional nonlinear finite element program. Particular examples were given showing the modeling of the Eurosid 1 dummy.

The session demonstrated the advances that have been made in assessment techniques in the automotive industry, in turn originally developed by the aircraft industry, and the transfer that now is beginning to take place back to aviation. The value of detailed, careful recording of injury data was shown in the results from the Kegworth accident. The analysis of these data and subsequent reconstructions showed that axial femoral loading may not be the mechanism of femoral fracture in some impacts. The importance of using injury scores in analyzing injury patterns within an accident and also for generating statistical information on a series of accidents was shown.

Computer programs for assessing the effects of impact also were discussed. These are powerful tools, but they are expensive to use and tend to require considerable engineering judgement in their applications. Nonetheless, they are the only means of analyzing complex or sequential impacts.

Session III

Session III was devoted to presentations relating to the use of human surrogates in testing dynamic response to impact acceleration. Paper 16 (Frisch, Boulay, and Alem) described the design and development of an improved Hybrid III Anthropomorphic Test Device (ATD). After a description of the general uses of the Hybrid III, the authors discussed some of the deficiencies of the manikin including its lack of spinal compressive response, the lack of spinal axial rotation, and the inability to change the contour of the spine. The authors discussed the modifications that they had developed which also included a modified pelvis that gives more human-like space and weight characteristics and which also houses an on-board instrumentation system.

Paper 17 (Van Ingen-Dunn, Richards, and Kaleps) dealt initially with manikin development from the Grumman Aldersen Research Dummy (GARD), originally developed to give static inertial loading in ejection seats, to the Advanced Dynamic Anthropomorphic Mannequin (ADAM). The authors describe some of the limitations of ADAM: the lack of adequate biofidelity in the neck and poor limb segment mass distribution characteristics. The development of a new concept neck was detailed and encouraging data were presented on the performance of the new neck.

Examples also were given of work to improve limb segment inertial characteristics using composite materials and new fabrication techniques.

Paper 18 (Roberts) was concerned with the design and use of automotive crash test dummies and a general overview of the UK Transport and Road Research Laboratory (TRRL). The paper provided a general overview of some of the problems in design, development, and calibration. The effect of impact vector on design was illustrated by reference to the variations in construction of frontal and side impact dummies. It was stated that TRRL preferred to use the OGLE OPAT dummy in preference to either the Hybrid II or Hybrid III when testing restraint systems. It was claimed that these latter dummies did not possess the right characteristics for restraint system testing as they had been developed for the evaluation of unrestrained occupants and air bags. The role of TRRL in the development of Eurosid and a mathematical representation of this in DYNA3D also was discussed.

Paper 19 (Newman, Zellner, and Wiley) was concerned with the development of a modified Hybrid III dummy to improve its usefulness in motorcycle-to-car crash testing. The modifications included a modified neck, to ensure the correct presentation of the helmeted head during the crash, changes to the lumbar spine to produce greater flexibility and provide the correct sitting angle, an abdominal insert to assess penetration depth and modified frangible lower legs to give an appropriate kinematic response after leg fracture. The details of the modifications were given together with the data from cadaver validation tests.

Paper 20 (Glaister, Waugh, and Neil) dealt with the use of a standard instrumented Hybrid III in the assessment of the occupant response to water impact in a free-fall lifeboat.

Paper 21 (Weiss, Willems, Mugnier, and Pittmanet) described the application of magnetohydrodynamic angular motion sensors to a revised sensor package for measuring head/neck dynamic response to impact. The analyses of the tests showed that the new sensor and photogrammetry system compared favorably with a 9-accelerometer array. The study confirmed the new system as being simpler, more accurate, and more portable than the one previously in use at the U.S. Navy Biodynamics Laboratory.

Session III showed the advances that have been made in improving dummy biofidelity. Z- and Y-axis responses continue to be a problem and dummy designs and modifications to improve responses in these axes were demonstrated. It is to be hoped that some of these modifications will be developed, standardized, and marketed.

The different approaches to dummy development were in evidence. The U.S. Air Force is the only organization using ADAM, the cost of this dummy being a major inhibitory factor for other agencies. Other laboratories appear to be converging on variants of the Hybrid III. This particular ATD is available with extensive instrumentation and has both regulatory and impact injury research applications. A plea for greater communication between those engaged in automotive and aviation impact research was entered. Session III clearly demonstrated the commonality of the disciplines involved and the advantages to be gained by better communication. Whether the appropriate vehicle for fostering this is AGARD, is for others to decide.

Session IV

Six papers presented in Session IV were related to fixed-wing accidents. They were divided into two homogeneous groups, one exclusively addressing F-16 accidents (papers 22 to 24), the other addressing in more general terms fixed-wing accident data and causal factors in the Belgian, French, and Hellenic Air Forces (papers 25, 26, and 28). In both groups, only class A mishaps (loss of aircraft, life, or damage exceeding $1 million following the U.S. definition) or equivalent were considered.

Vanderbeek (paper 22) made an exhaustive review of U.S. Air Force F-16 mishaps since 1984. Out of 120 mishaps, 65 were attributed to human error and resulted in 42 fatalities. Starting with the classical categorization where loss of situational awareness and spatial disorientation represented the causal factor in 28 cases, an expanded concept of mishaps causality was proposed in an attempt to include operational reality in the analysis. Six situational awareness subsets were defined and, reanalyzing the 65 mishaps, he assigned a "primary causal subset of degraded situation awareness" to 56 cases. This new classification was intended to demonstrate the preeminent role played by tactical and performance awareness at the origin of the mishaps. In a second section of the presentation, a program developed by the Tactical Air Command to improve pilot attention and awareness was discussed. This program, called the Aircrew Attention and Awareness Management Program currently is introduced at different levels of training for TAC pilots.

F-16 mishaps in the Royal Norwegian Air Force were examined over a 10-year period starting in 1981 (paper 23). During this period, 12 aircraft were lost due to in-flight mishaps, human factors were involved in 9 cases and among these, 6 fatalities occurred. The loss rate was 9.2 per 100,000 flight hours by the end of 1991, which is slightly better than the average of other European Air Forces using F-16. The study addressed several questions such as the concerns of investigators regarding human factors, the methods they used, what they reported, and what recommendations they made. Regarding these two last items, the classical human factor causes of accident were evoked with a particular emphasis on lack of continuation in flying, "get-it-done-itis" and channelized attention. Recommendations bore essentially on tactical awareness problems and some physiological concerns. Several points are of interest in improving investigation of the human factor in accidents. These include taking into account the flight safety potential of the mishaps, correct reconstruction of the events, mechanisms of errors, and sociopsychological considerations.

The Belgian Air Force was the first in Europe to introduce the F-16 into operational squadrons (paper 25). Since 1979, the Belgians F-16s have suffered high attrition rates. Their current rate is 14 per 100,000 flight hours after being as high as 20 from 1980 to 1983. Such high rates partly were due to mechanical failures occurring in the early years, but also due to the drastic increase in maneuverability and performance of the F-16 in comparison to the previous generation fighters used by Belgian pilots. Human factors causes represented a large portion of the primary accident cause factors ascribed to these accidents (current rate 9 per 100,000 flight hours). Four aircraft were lost in flight operations related accidents, five in controlled flight into terrain and six in midair collisions. Management problems in a particular squadron have resulted in an increasing trend in accident rates. After identification of this problem, which was not obvious, and subsequent correction, the Belgian Air Force mishap rate returned to a level comparable to other European nations using F-16s. This example clearly demonstrates the value of a thorough human factors investigation in the accident investigation process.

It should be noted that the three papers dealing with F-16 accidents, given by authors with a flight surgeon background, mainly stress the role of tactical and performance awareness problems (following the classification proposed by Vanderbeek). Interestingly, the recommendations of the inquiry boards resulted in corrective actions such as enforcement of flight procedures and regulations and specific training to improve situational awareness and management decisions.

This trend and the effectiveness of corrective actions was confirmed by the review made in the Belgian Air Force over a 21-year period, reported by Biesemans (paper 26). The authors addressed both combat and training aircraft mishaps. During the period, 114 aircraft and 62 pilots have been lost by the Belgian Air Force in peacetime operations. The overall rate of attrition was computed at 10.8 per 100,000 flight hours, with a rate of 14.3 for combat aircraft. Globally, operational factors were involved in 71 percent of the mishaps. Their analysis showed that the accident rate increased to a rate of 16 over the past 12 years. This increase coincided with a drastic reduction in pilots' annual flight hours to a historical low of 120 hrs/year, the introduction of the agile F-16, and a deficiency of experienced pilots in the squadrons. The problems of decreasing flight hours and pilot experience are compounded by cuts in military budgets. This situation calls for increased awareness and a more active role of management and flight safety personnel at all levels.

The survey made in France and reported by Ossard (paper 25) covered a 24-year period from 1977 to 1990. Some 210 mishaps were reported, leading to an overall rate of 3.7 per 100,000 hours. Most of these accidents were related to combat aircraft (72 percent). Apparently, the introduction of new generation aircraft, Mirages F1-CR and 2000, did not affect this proportion although the specific rate related to this category appears slightly higher than with other aircraft. The human factor remains the predominant causal factor in mishaps (63 percent), but paradoxically is less frequently involved in combat aircraft than in training aircraft. Fatalities occurred in 46 percent of the cases with a clear and regular decreasing trend since 1987. Regarding the new generation of fighter aircraft, a delay of 3 to 4 years before recording the first accident after introduction in operations was observed generally. Spatial disorientation and loss of situation awareness were mostly involved as the cause of the mishaps No G-LOC mishaps were reported.

Human factors were presented as the dominant cause of accidents in the Hellenic Air Force with a particular emphasis on pilot error (papers 27 and 28). The analytical study classified accidents into several groups including pilot related factors and environmental stressor effects. Inadequate flight training was the most frequently invoked cause and psychological factors also appeared to be a problem. Categorization of pilot error fell into the classical categories usually recognized. The trend in the Hellenic Air Force is toward significant progress in flight safety issues, while some concerns are raised with the introduction of new generation aircraft.

The epidemiologic analysis of fixed-wing aircraft accidents shows very clearly that combat aviation pays the heavier tribute to operational readiness. Despite some concerns regarding the introduction of new generation aircraft with totally new capabilities, it seems that there is little ground to think that air operations will become increasingly dangerous, at least during peace time. As a matter of fact, the decrease in fatalities observed in the French, which could probably be matched by identical observations in other NATO air forces, may definitely be related to technological improvement in escape systems (ejection through canopy, 0/0 rocket propelled seats, and so on). It still remains that the category of mishaps falling into the spatial disorientation problems, particularly type I disorientation (unrecognized), are unanimously demonstrated as generating a very high fatality rate. This aspect was particularly developed in Session V.

Session V

This session dealt primarily with spatial disorientation as an accident cause factor. Paper 31 addressed epidemiologic aspects of disorientation and accidents in fixed-wing aircraft, while paper 32 dealt with disorientation problems in rotary-wing aircraft.

Lyons (paper 31) reported that spatial disorientation continues to be a major contributing factor in 14 percent of accidents in fixed wing aircraft over a 2-year period. Nine of the 13 accidents recorded were fatal. A review of the accident database was made to investigate the way spatial disorientation factors were codified by investigators. Coding generally was found to be quite inconsistent with some evident misclassification and sometimes revealed a lack of understanding of the spatial disorientation problem involved in the accident. Differences also were found with accidents in the Navy, though some semantic variations could be involved. Definitional problems may contribute to the observed range in SD related accidents. The authors stressed the fact that spatial disorientation very often is indicated with cockpit attention contributing factors and that the distinction between loss of situational awareness and spatial disorientation is not really clear. Therefore, clarification of definitional and semantic issues seems to constitute a prerequisite to a scientific approach to the study of the problem.

Durnford (paper 32) presented the results of a questionnaire survey intended to gather information on the genesis and severity of disorientation episodes for pilots in the British Army. Spatial disorientation historically has caused 15-20 percent of accidents recorded and some recent changes in procedures, equipment, and training introduced a need for a survey of current disorientation problems. A high response rate (79 percent) was obtained to a questionnaire on disorientation episodes. Twenty-four percent of aircrew reported at least one severe incident of disorientation during their flying career and 6 percent had such a problem in the 4-month period preceding the survey. A review of different factors such as instrument flying, weather, and night flying, showed that this last condition contributed to an increase in severity and incidence of episodes. NVGs were involved in 44 percent of the cases where both crew had been disoriented. Disorientation appears to be a major concern, requiring improvement in equipment and of information displayed to the crew, and an increased awareness of problems related to NVGs, FLIR, and human factors considerations in flight safety.

In sharp contrast to the preceding papers, paper 34 dealt essentially with cognitive factors involved in accidents. Mainly based on the expertise of a cognitive psychology team, the data presented claimed that 87 percent of human factors mishaps over the past decade were of cognitive origin. Medical causes accounted for 6.5 percent, while physiological problems were present in only 2.5 percent of the cases. In an attempt to justify their findings, the authors referred mainly to a homemade and quite restrictive definition of spatial disorientation and sensory illusions which, as a matter of fact, is highly questionable. However the "in depth" analysis of the events recorded during the accident sequences lead to a very interesting, but theoretical description of human error mechanisms found as the cause of the mishaps. A "cognitively oriented" database has been developed to help improve understanding of the role of cognitive factors in flight safety.

Interestingly enough the meta analysis based on these different papers, especially on fixed-wing accidents, shows quite clearly that the field of expertise of the authors is highly correlated with interpretations made on the causes of accidents. Flight surgeons found mainly tactical awareness problems, physicians and managers stress the role of medical aspects and hierarchy problems, while physiologists regret the lack of understanding regarding their discipline and psychologists promote "all cognitive" issues. This demonstrates clearly that investigations should be reviewed by a multidisciplinary team and that a multinational accident database should include a large detailed description of objective material instead of more or less biased interpretations of the facts.

Papers 33 and 57 addressed several cases where disorientation problems were quite obvious and which were subjected to detailed investigations. A typical take-off accident involving a modern jet fighter is described in paper 33. The analysis of the flight parameters shows a quasimechanical relationship between otolithic inputs (calculated from Z- and X-axis acceleration data) and stick inputs before the pilot became severely disoriented and crashed on the runway. Visual cognitive information of attitude presented in the HUD had apparently not been used, the pilot behaving as if using a pure sensorimotor mode instead of a representational mode of spatial orientation. A correct understanding of the interfacing processes between the different modalities of spatial orientation then could constitute a key issue for the development of visualization and other devices aiming to alleviate disorientation problems, especially in helmet mounted systems.

Instead of dealing with a specific mishap, paper 57 reported four cases of disorientation problems which were investigated using the Pensacola Vestibular Test Battery. Three of the aircrew were referred for severe in-flight disorientation problems, the last being a survivor of a helicopter crash. With one exception, all pilots were found clinically normal, but demonstrated on further testing, some perceptual anomalies in attitude perception. Among several recommendations, the author stressed the need for a thorough screening of flight applicants, the use of specific spatial orientation testing, and building of a normative and pathological response database. A predictive model of perceptual response to acceleration stimuli also would be helpful for elucidating mishap causes and for designing improved man-machine interfaces to prevent spatial orientation. It is interesting that both papers explicitly support the view of a dual aspect of spatial orientation, sensorimotor and representational/perceptual as being part of a common process which cannot easily be disassociated and have to be taken into account as a whole.

An experimental simulator study concerning the effects of medium blood alcohol levels (up to 0.8 percent) on helicopter pilot performance was presented in paper 35. Pilots were tested on a 2.5-hour simulated IFR flight with and without alcoholic intoxication. Performance data recorded during the flight were compared for the two conditions. Major errors in radio communications, navigation, and helicopter control were recorded for intoxicated pilots, but those with an extensive experience were less prone to such errors than less experienced pilots. Nevertheless, the crews never failed to correctly execute emergency procedures even when under the influence of alcohol.

Session VI

Session VI was devoted to the epidemiology of rotary-wing accidents. Four of the papers focused on ditchings. In recent years, there has been an increased interest in NATO services in helicopter ditchings. Efforts have been focused primarily on issues relating to prevention and escape from a submerged aircraft. The first four papers (36,37,38, and 39) by Steele-Perkins, Brooks, Giry, and Barker presented excellent summaries of the ditching experience in the Royal Navy, the Canadian Forces, the French Navy, and the U.S. Navy. Their findings can be summarized as follows: (1) over half of ditchings are due to mechanical failure; (2) over three-quarters of ditchings are survivable; (3) ditchings uniformly involve rapid inversion and sinking of the helicopter resulting in most deaths being attributed to drowning; (4) escape and survival training, particularly using dynamic training devices, vastly improves occupant survival; (5) underwater lighting systems and portable emergency breathing devices improve survivability. Steele-Perkins also noted that most deaths occurred in disorientation mishaps where the water entry was uncontrolled. The Royal Navy is developing peripheral vision displays and height warning displays to help prevent pilot disorientation over water.

The papers by Shanahan (number 40) and McEntire (number 42) discussed more general aspects of helicopter crash survivability. Shanahan reviewed the 12-year crash experience of the U.S. Army Black Hawk, the first helicopter designed to modern crashworthiness standards. This helicopter has consistently provided occupant protection in crashes with vertical velocities up to 60 ft/s. This performance distinctly proves the validity of the crashworthiness concepts incorporated into the Black Hawk design and has been responsible for saving numerous lives.

McEntire presented data showing that the current design of inertia reels used in helicopters is not providing appropriate locking under all crash conditions. He has documented numerous cases where belt-extensions of up to 25 cm have occurred before the reel locked. This situation has resulted in many serious injuries. He suggests that a new performance design standard is needed that addresses all potential helicopter crash environments and that considers the lower onset rates and peak accelerations experienced in helicopters equipped with energy attenuating landing gear and crew seats.

Kirkpatrick (paper 29) discussed the results of a study investigating task errors and associated problem areas causing U.S. Army rotary-wing accidents over the period 1984 to 1991. The most frequently identified task errors, encompassing over 50 percent of errors, were improper decision, improper attention and inadequate communication. The most frequently identified problem areas were inadequate crew coordination and improper scanning. The U.S. Army Safety Center has initiated corrective measures intended to reduce the occurrence of the identified errors.

Session VII

Session VII included three papers addressing different aspects of rotary-wing accident and injury prevention. Licina (paper 43) presented a paper describing the U.S. Army Aviation Life Support Equipment Retrieval Program. In this program life support equipment is retrieved from crashes and personal injury data are correlated with the item of ALSE, the crash dynamics and documented aircraft structural damage. These data are entered into a database that is used to identify design deficiencies and to substantiate the need for system improvements. The program has had remarkable success in improving ALSE and in providing the basis for new design criteria over the two decades of its existence. Similar programs in other services would serve to strengthen the database.

Alem (paper 44) discussed the results of preliminary work directed toward establishing the efficacy of the concept of employing airbag restraint systems in attack helicopters to prevent serious head and upper torso injuries due to striking the gunsight. Using mockup front cockpits of the Apache and Cobra helicopters mounted on a horizontal sled accelerator and a modified Hybrid III manikin, the researchers noted markedly reduced indices of injury when standard automotive airbag systems were mounted to the gunsights. Based on this preliminary work, more detailed design concepts are being explored with the goal of using a 3-bag airbag system in the new Comanche helicopter.

In the final paper of the session, Shively (number 45) discussed efforts at NASA-Ames Research Center to develop a preflight risk assessment system (SAFE) for use by operators of emergency medical service helicopters. Initial tests have shown poor correlation of SAFE to pilot perceived risk and workload, but the authors are optimistic that efforts to refine the system will improve its validity. They maintain that by incorporating more data sources and with the proliferation of personal computers that this or similar systems will become an important aid to aviation safety.

Session VIII

Session VIII consisted of four papers oriented toward fire and the toxicological investigation of aircraft accidents. Winterfeld (paper 46) presented a synopsis of the 1989 AGARD Propulsion and Energetics Panel symposium on aircraft fire safety in order to stimulate exchange between the PEP and the AMP. He suggested that fire hardening of aircraft had increased considerably survival times, but that the prospects for additional improvement in this area were not encouraging. He expects that future progress will be achieved through systems designed to protect occupants from the consequences of fire, namely heat and toxic fumes. Development of these systems will require the participation of medical and other human factors experts as well as engineers. Therefore, he stressed the need for additional cooperative research and development.

Kerguelen presented a paper (number 47) addressing toxic fumes released during cabin fires and the effects a decrease in atmospheric pressure may have on the toxicity of the fumes. Realistic fire conditions were duplicated in the laboratory and thermolysis products of six materials commonly used in cabins were analyzed. To evaluate the toxicity of the released fumes, the mouse was used as the animal model. The study showed that lowering atmospheric pressure to 700 from 1000 hPa slightly altered the chemistry of the thermolysis, but significantly increased the toxicity of the generated gas mixture in which carbon monoxide and hydrogen cyanide were predominant. The authors offered convincing explanation, supported by the literature, which relate the blood concentration of toxins to partial pressure of the oxygen in the inhaled air. The study demonstrated the need to account for pressure in evaluating toxic gases released during thermolysis. However, the produced data have not been used to establish or recommend new standards for fire testing of materials used in aircraft cabins.

Powitz (paper 48) discussed techniques employed by the Aviation Pathology Group at the GAF Institute of Aviation Medicine for performing toxicological analyses of pathological specimens recovered from aircraft accidents. He stresses using caution in making a determination of "smoke in the cockpit" based on detecting pyrolysis products by gas chromatography. Inhalation of kerosene and fasting blood produce similar patterns. Likewise, he notes that tissue immersed in sea water can absorb bromine and this process must be distinguished from premortem use of bromine containing drugs. He also provided evidence that current gas chromatographic methods of detecting alcohol in biological specimens may produce falsely elevated values due to bacterial putrefaction occurring during the analytical process.

The final paper of the session, presented by Mayr (number 49), reviewed the 27-year history of the Aerospace Pathology and Toxicology Department of the GAF Institute of Aviation Medicine. He also detailed the current organization of the department and described its methods and duties.

Session IX

Session IX focused on the role of pathological and histological examinations in aircraft accident investigation. In the first paper (number 50), Kramer stressed the importance of histological examination in the determination of accident causation. He notes that macroscopic postmortem finding are relevant to determining injury cause factors, but they are insufficient for determining accident cause factors. Histological examinations frequently are able to determine pathological changes related to preexisting medical conditions that may have been involved in the cause of the accident. In his experience, approximately 10 percent of cases have manifest histopathological changes. How many of these were determined to be related to accident causation was not stated. To support his thesis, he presented several illustrative case reports.

The last two papers of the session discussed patterns of injury found in aircraft accidents. Paxinos (paper 52) reviewed injuries sustained in crashes in the Hellenic Air Force during the years 1974-1990. Garcia Alcon (paper 53) presented an epidemiological study of ejections in the Spanish Air Force over a 5-year period. During the study period, there were 20 ejections with three fatalities. From an analysis of these ejections he reemphasized the importance of correct sitting posture and initiation within the prescribed safe ejection envelope. To improve both factors, he stressed the importance of training in ejection simulators and in parachute landings. He also noted the importance from a psychological standpoint of returning pilots to duty as rapidly as possible after an ejection.

Session X

This session comprised only four papers, and three of these, presented by Rejman and Symonds, emanated from the Human Factors Unit of the UK's Army Air Corps. In the first paper, Rejman (number 54) pursued the thesis that most accident research is "reactive" in looking back at the events of an accident, but that flight safety research should be much more "proactive" if it is to have any effect on accident prevention. Thus he has tried to identify those sources of data existing within his own organization that may act as indicators of risk and thus enable "proactive intervention."

Although the basic idea here is similar to that put forward by Rameckers in the opening session (paper 5), the approach was rather different. In the Rejman paper, organizational aspects of safety are addressed, and an attempt made to define, if not quantify, the "organizational ethos," but most of the study concentrates on generating a coherent database of selection, training, and operational assessment data. It already has been possible to identify critical types of training assessment pattern that may be useful.

The paper presented by Symonds (number 56) on prediction of success from training data appeared to pursue the same approach to the analysis of training data as that referred to above, but used the data in order to attempt to predict overall success in flying training. Although the techniques described probably represent some advance in the way in which training data can be analyzed, and the "error rating profiles" that are produced by the analysis may be used in screening for potential safety risks, the main thrust of this paper was in the direction of predicting flying training success rather than future hazard--though these factors may well be related.

The second paper presented by Rejman (paper 55) took a traditional human factors approach to a review of recent British Army Air Corps accidents, but was interesting in attempting to categorize the same set of accidents in terms of three different categorization systems or taxonomies. The comments in the Rejman paper on the relative utilities of the systems he used, and the difficulties that he encountered in assigning accidents to causal categories, are worth noting for others who may be in the process of generating or using such databases. His work was limited, principally, by the relatively small size of the accident sample that was available to him, and a replication of this work using a larger sample of accidents and a wider variety of categorization systems could well be useful.

The final paper in this session was presented by Myhre of Norway (number 58) and addressed the issue of whether females on modern flight decks were different from male crew members in ways that required addressing in flight deck or cockpit resource management programs. Although this paper had nothing to do with accident investigation, it made some points that were related to safety. Perhaps the main one was that the paper highlighted studies that indicate that men and women communicate in rather different ways, with women tending to send rather less "direct messages than the men, who are more "matter of fact" in their interactions. The impact of this and other sex differences are discussed in this most speculative paper, but because of this speculative approach, little by way of firm conclusion was reached.

Session XI.

Tarriere (paper 59) investigated individual stress susceptibility in regard to accident avoiding behavior in cars. One hundred subjects were tested at a car track test facility after being screened for stress reactivity. Physiological data were recorded during the tests, which consisted of a collision avoidance task using standard and ABS brakes. Physiological and psychological tests were found to be correlated with success in performing the manoeuver, though some concerns were raised in the audience about the effect of an unbalanced experimental design, especially in regard of ABS efficacy. The reliability of the physiological measurements also was questioned.

Of more interest, paper 62 dealt with a system using physiological indexes to detect vigilance impairment in automotive drivers based on real time analysis of steering wheel movements. During the design and proof of concept phase, the level of vigilance was evaluated using EEG and EOG associated with a video analysis of driver behavior. Some preliminary results showed that early detection of hypovigilance episodes is improved significantly through the analysis of EOG recordings. Such a physiological reference should be helpful in evaluating the results from the steering wheel movements analysis.

Paper 61 also addressed the interest of some physiological measures in regard to safety problems during vehicle piloting tasks. The power spectrum of heart rate showed a sensitivity to mental effort, particularly in the frequency range 0.02 to 0.05 Hz. This effect was demonstrated during speech recognition tests at rest versus real situations in train engineers and pilots, though not systematically present during tasks requiring increased attention. There was no correlation with task difficulty or operator performance, but some with the mental effort realized by the subject. This method should be useful to evaluate the activation of the adrenergic system and subject involvement in the task.

The paper by Heron (number 60) did not describe any completed work, but described how a Canadian group is hoping to use a basic aircraft simulator to train pilots in handling emergencies. During the training, they will be monitored in a number ways to include both electroencephalographic and magnetoencephalographic techniques. Since this program is confined at the moment to preparation and hope for the future, little can be said about it. Many will regard it as surprising, however, if the rudimentary nature of the proposed simulator and the gross nature of the envisioned physiological measures are capable of producing useful results.

The final two papers of the meeting were delivered by Cetingue (numbers 63 and 64). In the first, he identified a number of "hazardous thought patterns" that he termed "gremlins." These "gremlins" included accident proneness, macho attitude, impulsivity, phobic and counterphobic behavior. He concluded that pilots should identify their own hazardous thought processes, be aware of them, and take steps to keep them under control.

The last paper (number 64) consisted of another look at the biorhythm myth. It is difficult to avoid the notion that the only surprising thing about "biorhythm" theory is that anybody should ever have found it remotely plausible. Nevertheless, a number of researchers have examined large numbers of accidents, and related these to the dates of birth of the pilots involved to see whether there was any correlation with the hypothesized biorhythm cycles. This paper, like the others, found no such relationship. If this presentation tells us anything, it is surely that there is no magical solution to the problem of explaining human error. Errors made by systems as complex and changeable as human beings will require models that are just as complex. Simple solutions simply are not available.

6. CONCLUSIONS

6.1 Complete and thorough accident investigations provide the basis of a successful accident prevention program. The medical portion of the investigation requires an integrated approach using a multidisciplinary team of human factors, engineering, and medical experts.

6.2 With the increasing reliability of aircraft systems, weather forecasting and avoidance systems, and navigation systems, the vast majority of accidents will continue to be due to human, primarily flight crew, error.

6.3 To effect a reduction in human error accidents, more emphasis needs to be placed on the human factors portion of aircraft accident investigations. This emphasis must be supported by cooperative human factors research.

6.4 Accident investigation teams should include human factors experts.

6.5 Given that accidents will continue to occur in spite of all efforts to the contrary, all aircraft should be made more crash survivable. The major efforts should be placed on fire prevention and control, structural integrity, and occupant restraint. In smaller aircraft, energy attenuation systems also must be considered.

6.6 Direction for improvements in aircraft crash survivability must be based on priorities established through thorough injury investigations. These efforts must be supported by coordinated scientific research programs.

6.7 As in the investigation of human error causes, too little emphasis has traditionally been placed on injury investigation.

6.8 To best ensure professional and unbiased judgements, accident investigation teams should be comprised of professional investigators who are completely independent of the organization to which the accident aircraft belongs.

7. RECOMMENDATIONS

7.1 The tremendous response by authors to the announcement of this symposium indicates the intense interest of the AGARD community in aircraft accident investigation. AMP should consider convening future conferences dealing with specific topics related to accident investigation.

7.2 Aircraft accident investigation boards should routinely include human factors expertise.

7.3 Agencies responsible for convening an aircraft accident board should guarantee the independence of that board to the extent possible.

Human Factors in Aircraft Accident Investigation

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I am delighted to deliver the opening lecture to this meeting and I recognize what a privilege it is to do so. This is especially true given the level of expertise and experience that is so obvious in both the audience and speakers. I also feel extremely pleased that although this meeting is about trends in aerospace *medical* investigation techniques, it is a psychologist and not a doctor delivering this opening lecture.

I might just observe here that I feel that it is absolutely right that the disciplines concerned with the human factor in aviation should come together at meetings such as this. The only difficulty that I see is what to call the aggregation of physiologists, physicians, psychologists, ergonomists, anthropometrists, and even sociologists who may have a contribution to make. I think that since all of these disciplines are concerned with the 'human factor' in aviation, it makes sense to call all of them 'human factor' pursuits of one sort or another, and not to reserve this term for applied psychology or ergonomics as sometimes happens.

I am not suggesting that the practitioners in these disciplines should lose their individual skills or group identities, and I certainly would not wish to suggest that they can do each other's jobs, but I do hope that they will all realize the part they have to play, interacting with one another, in the overall human factors picture. I think that I am probably pushing at an open door in canvassing such views at this conference. The ICAO and ECAC syllabuses in human factors for pilots already take this integrated, multi-disciplinary view of the subject area of 'human factors', and I am sure that this integration of approach will become increasingly prevalent in future.

Because I am a psychologist and not a doctor, however, I will not attempt to review the role of the physician in accident investigation, but I will try to identify some problem areas that I see for psychologists, in the hope that some, perhaps all, of the factors I address will have a broader significance in the human factors community.

I would like to begin by discussing briefly two very basic psychological effects that can cause both pilots and accident investigators to err. The first is one of the most important psychological causes of human error accidents, and is the family of effects sometimes referred to as 'hypothesis locking' or 'confirmation bias'. For the non-psychologist, I should briefly explain that these effects concern the tendency that people have to be reluctant to change their mind - even when they really should - and I would like to give a couple of examples.

The first occurred to a British Airways 747 in the early 1970s. The aircraft was approaching Nairobi and had been given an intermediate descent clearance in which the controller told the aircraft that it had been cleared down to 'seven - five - zero - zero'. The 'seven' was not heard by the crew, and the stimulus detected by them must, therefore, have been 'five - zero - zero'. The first officer read back the clearance as 'Cleared to five thousand', but the air traffic controller failed to notice the error. Both the first officer and the captain had taken the incomplete information that they had received and massaged it a little, quite unconsciously, in order to convert the stimulus into a plausible, albeit inaccurate, percept.

More interesting was what happened next, however. The glide slope pointer disappeared off the top of the attitude indicator, a glide slope warning flag appeared, and the aircraft broke cloud at an extremely low altitude. Despite all of these cues the captain continued to descend, having dismissed the information that did not fit his mental model as either instrument failure or visual illusion. It appears that once this captain had generated a mental model with which he was happy, he was not to be shifted from it.

The second example of 'hypothesis locking' that I would like you to consider occurred on board the British Midland 737 that crashed at Kegworth, in the UK, just over three years ago. The left engine of this aircraft began to fail as it reached about 30,000ft, producing a smell of burning and a shuddering on the flight deck. The first officer suggested that there was a fire, and the captain said 'Which one [engine] is it though?'. The first officer gave his attention to the engine instruments and said 'It's the le . . - It's the right one.' An inaccurate mental model had been generated, and was confirmed for the crew when, on throttling back the right engine, the shuddering coincidentally stopped. There was evidence available to this crew from the engine instruments, especially the engine vibration gauges, that the left engine was continuing to be faulty. They could also have asked the cabin crew whether they had seen anything. Had they done so, they would have learned that flashes of glowing debris had been seen leaving the left engine. The crew, however, did not check their situational model by seeking to disprove it (it could be argued that they had never been trained to do so), and the aircraft was finally lost when, on final approach, the captain demanded power from the failing left engine, only for it to die completely.

The second effect, or set of effects, that I would like to mention concerns the social factors that influence crew behaviour on flight decks, and the example that I would like to use comes from the database of the UK Confidential Human Factors Incident Reporting Programme (CHIRP). In this incident, a commercial jet containing a three man crew had already been forced to overshoot its destination runway twice because of bad weather. The crew took the aircraft into a hold in order to plan their diversion when they heard that another aircraft had just landed at their desired destination. Their company rules were clear - they must divert - but the suggestion was made by one crew member that they should have another attempt at landing, but this time reducing their decision height (illegally) by 50ft. This was rejected by the other crew members, but they managed to agree to another suggestion that the aircraft should be flown down to its decision height, flown level at this height until runway lights were seen, then the approach resumed.

Those familiar with flying will identify a disaster waiting to happen here, and those familiar with a little social psychology will see the effects of both 'risky shift' (groups tend to make more polarized decisions than individuals), and 'compliance' (people will generally be more likely to agree to an unreasonable suggestion if it has been preceded by an even more unreasonable one) at work. To complete the narration of the incident I should mention that the crew members carried out their plan but, not having seen the runway threshold lights, landed an unknown distance down the runway and carried out a maximum performance stop. The pilot filing the report commented that after stopping, silence filled the cockpit as the crew members realized that they had all been party to an act of 'supreme folly'.

My reason for beginning with these examples of a pair of well known psychological effects is not to attempt to inform the reader about them - though the participants in this conference come from a sufficiently wide set of backgrounds that I do appreciate that not all will be, or will wish to be, familiar with any social psychology - but to suggest that accident investigators as groups or individuals may fall into the same traps.

Accidents generally present the investigator with a number of cues or information points that represent only a subset of the total required completely to define the events of the incident. Sometimes this may be a fairly informative subset, if, for example, there is a surviving crew, cockpit voice recording, flight data recording, and good witnesses, but sometimes the available information can be very thin indeed. In any event, the investigator's job is to sift the data, to make patterns from it, and to generate a coherent model that pulls together as much of the data together as possible - if not all of it. We should beware of 'confirmation bias', however. It can be awkward when a piece of information comes along, after we have generated our accident model (or made up our minds), that does not fit, so it is very tempting to dismiss the new evidence as in some way unreliable or flawed.

Worse, we may have generated an accident model with which we are content, but which is not supported by enough evidence. At this point, of course, more evidence must be sought to support the model, but it is equally important, though more rarely done, to seek out any evidence that might undermine the model. Paradoxically, it is only by seeking assiduously to disprove our ideas and by failing to do so that we can ever have any real confidence in them. Many of those involved in accident investigation will be familiar with the truth of this notion, but may find it much more difficult to put the principle into practice.

It seems to me that there may also be a danger of 'confirmation bias' and the social effects outlined above influencing conferences such as this. The temptation at a meeting is to reinforce one another's common beliefs. This is particularly obvious at political party conferences. Nobody attends one of these in order to learn anything or to have his views or practices subjected to critical question. They are meetings of the faithful, held only in order to reinforce, by the laws of social mass action, the strength of belief of the individual participants. But this should be no way for a scientific meeting. I suggest that the atmosphere should be questioning, and the questions should be about whether there are ways of progressing in accident investigation that have not been properly considered, whether there are ways of flying being introduced that have changed the types of errors that people make, and whether there are alternative ways of considering the nature of human error that might lead to different insights into the problem and its solutions.

None of this is to suggest that we have been wrong in the ways that human error has been tackled in the past, but flying is changing, most notably in terms of the way the flight deck has become automated. It is important for the accident investigator to be familiar with the ways in which the relationship between the pilot and his aircraft may be influenced by this technological change.

Some of the changes wrought by automation in the cockpit (and the errors that accompany these changes) may be trivial, and identical to the changes and errors occurring in other situations. When I first used a word processor, I saved a file by the name of an already existent file and, to my real annoyance, lost it completely. When I was recently in North America there was an item on the news that a 'flunkey' (computer operator) in a leading stockbrokers tried to sell $11,000,000 of shares for a client but keyed the wrong instruction and instead sold 11,000,000 shares worth about $500,000,000. This was sufficient to trigger the automated share dealing facilities of other stockbrokers, and for the Dow Jones Index to drop notably before the error had been discovered - but nobody was hurt. In the recent A320 Strasbourg accident, however, a pilot intended to enter a demand for a 3.7 degree glide slope into the aircraft's flight management system, but instead entered a demand for a 3,700 feet per minute rate of descent. The aircraft crashed with considerable loss of life.

All of these errors are the same, of course, only the consequences differed, and it might be argued that they could have happened just as easily on non-automated equipment. It may be, though, that the automated flight deck does change the nature of the pilot's relationship with his machine in special ways. Putting a computer between the pilot's instruments and the environment has distanced the pilot from the real world, so that the cockpit displays, instead of being useful hints and tips that enable the pilot to create a mental model of reality, have now become that reality. The pilot no longer has to work at generating a world model containing real poor weather and real mountains, he simply has to follow the magenta line: the display has become his world. The system may have become so complex that the pilot cannot hope to understand how it works in the same way that he could understand how an old fashioned altimeter works, and so has no alternative but to believe what the screen says.

If this is true it will be impossible for the pilot to question his model of the real world since he no longer has one. It could be argued that this effect underlies many of the accidents that have already happened in automated aircraft: crews believed that their situations were safe because they trusted - perhaps overtrusted - the aircraft, the displays seemed normal, and they did not have a clear idea of what constituted external reality.

Clearly, it is up to accident investigators not just to comment on or to explain the circumstances of individual accidents, but to put together information from as many accidents and incidents as possible in order to extract general principles, and nowhere is this called for more at the moment than in the area of automation.

I must mention one other problem area, however, and that concerns how deeply to probe and where to stop investigating. If a display appears poorly designed, the investigator will obviously comment on it. Is it, however, the investigator's job to discover why the person who did the test flying on the aircraft felt that the display was acceptable? Should he discover what evaluation the manufacturer carried out on the display? Is it the concern of the investigator to analyze and to evaluate the safety 'culture' that exists in the organization that permitted the display to become operational? In the A320 involved in the accident described above, there was no GPWS (ground proximity warning system) fitted to the aircraft. Is it the task of the investigator simply to observe this, or is it his job to identify why the company and regulatory authority came to permit the absence of a device that many would regard as an indispensable item of aircraft safety equipment?

Issues such as these are increasingly becoming of concern to accident investigators as the focus for investigations spreads from the individual in the cockpit to the entire system that results in a given pilot flying a given aircraft on a given day.

There are, however, real problems with this extension of the investigation, and I would like to highlight three of them here. The first is that the organization which accepts philosophically that one of its individual pilots has made an explainable error may be less sanguine about accepting that its own management, structure, and attitudes are partly responsible for the accident. Furthermore, the power of organizations is such that it may require a much more determined and resolute investigator to be as bold about identifying faults and shortcomings in an organization (especially if it is the organization that employs him) as he may be about identifying the errors of the individual.

The second problem is related to the issue of 'blame'. There has always been a conflict between the requirements of the accident investigator and those of the disciplinary authority. For example, it is desirable for the investigator to obtain a statement from, say, the pilot involved in an accident as quickly as possible in order to obtain the best available raw recollections, minimally tainted by the inevitable post accident rationalization. No lawyer, however, would permit a client to give evidence that may be held against him without the deepest possible consideration. Normally the investigator has claimed to be concerned only to analyze the facts and to come up with as objective a conclusion as possible, and to be unhappy to become embroiled in issues of negligence, culpability, or distribution of blame. If the organization is to be investigated, however, the question of the allocation of responsibility may well be more difficult to avoid, especially since the legal and financial sequelae of being identified as falling short of ideal performance may be very considerable for an organization and its management.

The third problem concerns the skills and training of accident investigators. The importance of physiological factors in aircraft accident causation and analysis has long been recognized by the occasional use of medical officers on accident boards. This has given way to a more formal involvement of such doctors, with the disciplines of investigatory medicine and pathology in aviation becoming increasingly specialized. The importance of behavioural factors in accidents has been recognized increasingly during at least the last twenty years by the inclusion of psychologists on accident boards, and it is notable that the Australian Bureau of Air Safety is now headed by a psychologist.

Who, though, is to investigate the organization, and should this be regarded as a human factors issue? The psychologists presently involved in accident investigation are drawn from a dominantly experimental or cognitive background and may well not possess the knowledge of management psychology needed to make an informed analysis of the factors within the organization that may have set the scene for the accident. Perhaps those presently involved in the psychological and medical investigation should be in the vanguard of those recognizing that new skills may be required and they should, perhaps, set about acquiring them. It may seem strange to many that an aircraft accident investigator may require a degree in business administration, but this may be what is called for.

Thus whereas our expertise in the investigation of mechanical, medical, and psychological aspects of accidents has reached a degree of maturity, the same cannot be claimed for organizational aspects. Indeed we know rather little of the influence of organizational factors on system failure and, given the sensitivity of organizations to self evaluation, this is possibly the most challenging field for the future.

To sum up, I have argued that although there is a natural tendency for people to cling to what they understand and to seek reassurance from the world that their established ways are right, accident investigators of all people must recognize the importance and necessity of change and of questioning conventional wisdoms. This applies not only to the way in which they might address the investigation of an individual accident, but to the ways in which they view the whole topic area. They must be ready to understand the changing nature of the pilot's task, and ready to change their own methods and ideas in order to keep pace.

I have resisted, so far at least, any use of statistics to emphasise the importance of the human factor in aircraft accidents. I would like to close, however, by observing that although medicine and psychology have been associated with accident investigation for a considerable period, and although many important, though arguably small, changes have taken place in training, euipment, and procedures as a result of this involvement, we have still not made the major impact required to reduce dramatically the accident rate attributable to the human factor. This must be the goal, and we should not shrink from taking the bold initiatives, both in terms of our own thinking and in terms of pressing for adequate staff and resources, that will be required to achieve it.

HOW DO WE INVESTIGATE THE HUMAN FACTOR IN AIRCRAFT ACCIDENTS?

by

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SUMMARY

Historically, flight safety began as a technical consideration. Once the aircraft was ready to be used as a tool, the flight safety work expanded to become an operational issue.

Today, the reality is that two-thirds of accidents and incidents are related to Human Factors. The concept of Human Factors is hard to define, identify or verify and the definitions of the concept are as many as its advocates.

The Human Factor investigator belongs as naturally to the Investigation Board as does the technical investigator. In the past, all findings not attributable to causes in accidents were called pilot error. This may be true if you only look at the situational causes, but the responsibility for the underlying causes may lie elsewhere. The question of Human Factor concerns not only the pilot himself; he must be seen in the context of a human being and not only as an operator in the cockpit. The environmental factors are no longer a question of the relationship between man and machine. Today the influence of the company/organisation is a part of the concept of the Human Factor. The company has to give the pilot the best conditions in which to succeed in his mission - then the pilot assumes the responsibility.

In order to be aware of the complexity of the Human Factor in defining the root cause of an accident, to sub-categorise the concept, to be able to analyse and to see the trends over a period of time, trained experts are required.

In a small team like an Accident Investigation Board, it is necessary to learn how to communicate and very soon it can be seen what strength is gained from the different ways of approaching problems, due to the differences in the experts' professional backgrounds. Flight safety work should reflect this way of working. We all need each other's competence on the Accident Investigation Board. Our total findings, including the Human Factor findings, must influence the total report, which will form the basis of future flight safety work.

INTRODUCTION

Over the years, man has appeared more and more to be a limiting factor in flight operations.

The concept of flight safety was actually created at the same moment as the idea of flying was conceived It was basically a survival concept, which in a historical perspective was originally a technical question. Over the years, the concept of flight safety took on an operational dimension.

Achieving tactical solutions with as little inherent risk as possible, but without reducing effectivity, became the decisive factors in flight safety work.

Through experience, mistakes made in the air, incidents and accidents, rules and regulations for their prevention were and are established. Operational flight safety measures were taken.

Accidents and incidents have decreased drastically. It is mainly the technically related accidents which have been overcome. In order to go further in flight safety work there is a pronounced awareness of the necessity of focusing on man in the flight system. Two-thirds of accidents and incidents are directly related to the Human Factor.

THE CONCEPT OF THE HUMAN FACTOR

The concept of the Human Factor has as many definitions as it does advocates.

Originating from a world of scientific notes, research into the integration of man and machine (ergonomics) was initially synonymous with the concept of the Human Factor. In the USA this definition is that which is still most widespread.

Over the years, the concept of the Human Factor has, however, achieved a broader scope. The human in this respect is not synonymous with the individual pilot, but also includes the conditions he has been provided with in order to succeed in his task seen from the outside - from the design of the aircraft he is to operate in, to central management's responsibility for having chosen that particular person to solve this task (selection), and the way in which he is trained for this purpose (training) to whether the staff who are in charge of operations are competent to do their job (management).

Apart from central management, the local management also has responsibility (leadership) for operations being run under the optimum flight safety conditions, just as the individual, the pilot, the engineer, etc. bears his responsibility to achieve the requirements and standards expected of him (individual responsibility).

It appears that the concept of the Human Factor is a broad and less easily measured concept which faces certain difficulties in finding acceptance in an operation harbouring a scientific idea of the world. This can be described as collision between two world concepts. The fact is that we need both of them. The accident and incident statistics as much as anything else express clearly the need for a systematic and structural approach to getting at the underlying causes hidden in the Human Factor concept.

INVESTIGATION HISTORY

The first systematic accident investigation carried out took place as early as 1909. It was the then sensational accident as a result of Orville Wright's attempts to demonstrate the performance of his aircraft. The aeroplane crashed and the passenger Tom Selfridge was fatally injured (Jensen, 1989).

Accident investigations have, and have had over the years, a technical profile on the analogy of the developments within aviation. The accident investigator was drawn by tradition from the operational and technical ranks. Accident causes which could not be attributed to technical reasons were usually labelled pilot error. A description of what had happened was given, but seldom a description of why it happened.

At the twentieth IATA (International Air Transportation Association) conference in 1975, the view was expressed that "there is an urgent need for the inclusion of Human Factor experts in all accident investigation teams" (Hawkins, 1987). IFALPA (International Federation of Airline Pilots Association) considered in 1977 "that Human Factor aspects of accident/incident investigation should be more deeply pursued" (Hawkins, 1987).

The shortage of Human Factor experts has shown itself to be acute. The growth of the experts within the Human Factor field has been limited for obvious reasons, as the aviation industry, as well as the flying establishment in general, has previously been unwilling to bring in and apply knowledge of this kind.

At the end of the 1970's and the beginning of the 1980's, however, aviation psychologists were increasingly attached to accident investigation boards in the USA, Australia, Canada, UK, etc. In Sweden there has been a Human Factor expert on the Board of Accident Investigation for investigating primarily accidents in the defence sector since 1982.

THE CRITERIA FOR HUMAN FACTOR ACCIDENT INVESTIGATION

In order to map out and illuminate the purely technical function, it is possible to use sophisticated technology to produce data on how the pilot has used the aircraft operationally when an accident occurs.

It is much more difficult and most of all far more sensitive to try to analyse human and organisational responsibility in this context.

A Human Factor investigator is in many ways his own instrument, which is why maturity, self-discipline and the ability to reach people and be accepted are of prime importance.

The task of "undressing" a person or an organisation can be a delicate balance between showing consideration and respect for the individual and endeavouring to find the truth. This requires that the investigator has the motives and goal clear in his mind, but makes his way forward with humility. This should be founded on a confidence which is based in the world of aviation.

Besides a solid academic professional background, one needs a good knowledge of pilot requirements, knowledge of the educational and operational requirements as well as of the organisational structure.

THE ACCIDENT INVESTIATION BOARD IN SWEDEN

The structure of the accident investigation board differs considerably from country to country and from civilian to military operations. The aims and goals are, however the same, which means - to make flying as safe as possible.

The investigation board in Sweden is an independent authority, which covers all major accidents and incidents in aviation, military as well as civilian.

The Board employs quite a number of people and its philosophy lies in attaching to itself, at each individual accident, well-trained investigators each working within their specialist areas and well-established in flight operations.

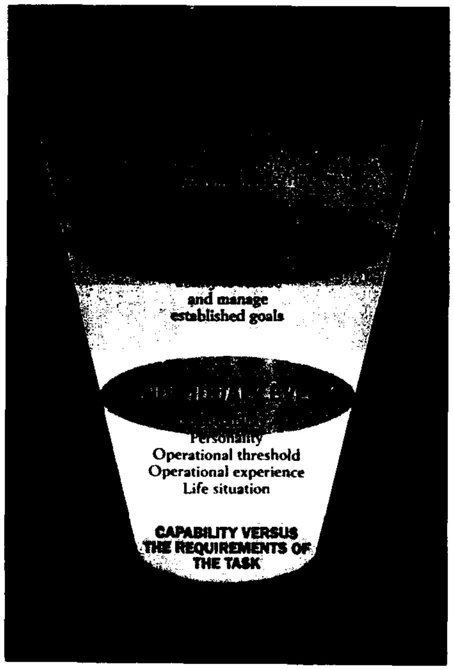
The president of the board is always a legal expert, however he does not sit as a judge, but balances the respective experts' investigation results against one another to make a final report.

The accident investigation board is constituted at its first meeting immediately in connection with the occurrence of the accident. The board's investigators represent the operational, technical, medical and Human Factor areas. All hold an independent position in the investigation board but work closely together. Experts from other fields are brought in when necessary.

THE ACCIDENT INVESTIGATION PROCESS

All members of the investigation board are present during the initial questioning of the parties involved in the accident. This means that they all receive the same information to work form.

The next step is for the respective investigators to independently take up their own specialist area. By analysing available documentation and interviews the Human Factor investigator has to map out, interpret and assess areas which affect:



During the course of the investigation a number of meetings of all the investigators take place, to compare notes, exchange information and discuss the future direction of the investigation.

In the final stage of the investigation the respective investigators responsible present their fact finding and their analysis so that they can, after discussions and joint analysis, reach the most credible course of events and underlying causal factors.

The handling of the Human Factor investigator's documentation may still vary in Sweden, depending on the wishes of the president of the board. That the written documentation should be considered for "official use only" and not available to the public should be a matter of course. If not, then the written documentation should be thinned out and smoothed over so as not to damage the individual.

The Human Factor investigator's report, as those of the other investigators, should be seen as pieces of a puzzle, where all of the pieces are required to make up the whole.

All of the responsible investigators, including the Human Factor investigator, should be involved right from the start of the investigation and should as independent investigators, affect the investigation's final report. An accident investigation board thereby becomes a dynamic working team, dependent on the differences in professional backgrounds in the group, which gives it strength. Within the board everyone has to learn to communicate and the various areas of competence are necessary to get closer to the solution.

The final report, which is written by the president of the board, is examined by the responsible investigators at the accident investigation boards's final meeting. The final report is signed by the president of the board and is then an open document.

CONCLUSION

An accident can be seen as the most extreme form of failure in flight safety work. It is the most dearly-bought experience for flight safety work. In order to be able to take safety measures, thoroughly worked out investigation reports are needed, where the Human Factor investigator makes it possible to go a step further, to analyse the underlying factors. As man is evidently the weakest link in the system, the human mental conditions and the human management of the critical situation should be brought to light and analysed in order to add them to the experience bank.

The Human Factor investigator should, therefore, be as natural a member of the accident investigation board as the technical investigator, on all such boards throughout the world.

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A METHOD FOR INVESTIGATING HUMAN FACTOR ASPECTS OF MILITARY AIRCRAFT ACCIDENTS

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For most of us the term "human factor" denotes the relationship between the aviator, the aircraft and the environment. This covers a very large and complex interrelated panorama of factors, to include as an example, personal stress, training, physiology, aircraft flight characteristics, judgement and decision making, experience, nutrition, fatigue, motivation. There are many other factors we will discuss further along.

A major concern in assessing the significance of any particular human factor, or combination of factors, is the method employed in the collection of the raw data and subsequent analysis. I will first describe the method of investigation and analysis employed by the US Air Force, then discuss the problems inherent in this approach, and finally I will propose a joint, NATO human factors aircraft accident investigation methodology and program.

The US Air Force approach to aircraft accident investigation has changed little over the last several years. Immediately following an aircraft accident an interim or temporary safety investigation board is appointed, and usually functions for the next three days. The accident investigation experience of the members of this interim board varies widely but at least one member of the team has completed a formal academic and laboratory course of aircraft accident investigation which they may or may not have applied to a previous accident. This interim group of investigators searches for, collects and preserves aircraft and aviator remains, examines and interviews aircrew and witnesses, and assembles relevant data for presentation to the permanent accident investigation board, properly called the "safety investigation board." A separate "accident investigation board" or "collateral" board is convened to assess fault. The mission of the "safety investigation board" is to determine how future aircraft accidents can be prevented based on their analysis of the accident under investigation. The "collateral" board usually begins its investigation after the safety investigation board has completed its business and maintains an "arms-length" relationship with the "safety investigation board." The two processes are carefully separated and aircrew interviewed by the "safety investigation board" clearly understand the board's mission of prevention. The accident investigation continues over the course of approximately twenty days, followed by a detailed analysis of the accident, the construction of a formal report, and the presentation of this report to senior commanders (general officers) and the Air Force Safety Agency. The Director of Air Force Safety (a general officer assigned to the Headquarters staff of the Air Force Chief of Staff) reviews the safety investigation board's report and analysis, the analysis of the Air Force Safety Agency, and then concurs, adds or modifies recommendations for the correction of those problems leading to or causing the accident.

The human factors aspect of the accident investigation is the responsibility of the flight surgeon assigned to the permanent safety investigation board. He is usually assigned from a unit other than his own (to prevent conflict of interest or confusion of loyalty), and his unit usually flies the type of aircraft involved in the accident under investigation. U.S. flight surgeons are required to fly at least four hours every month in aircraft flown by the aircrews they provide medical care. Hence, the investigating flight surgeon is familiar with the mission, environment, and peculiar characteristics of the aircraft. He has deployed with his unit during exercises, experienced G forces in simulated combat, observed the effects of fatigue, dehydration and family separation, personally suffered motion sickness and spatial disorientation. He has been exposed to a variety of human factors that contribute to accidents during the course of his routine work. During the flight surgeon training course, he has received twenty hours of academic instruction in the investigation, analysis and prevention of aircraft accidents. The interval between the completion of this training program and serving as the medical member of a safety investigation board varies from three months to several years. Very few of our human factor investigators have investigated more than one accident during their Air Force career.

The permanent safety investigation board flight surgeon will usually go to the accident site and obtain a direct visual impression of the results of the crash and become familiar with the terrain. He will often do this at altitude in a helicopter as well as on the ground. At remote accident sites the board may bivouac in tents or stay in nearby motels if available, eventually convening to a nearby Air Force base or the base from which the accident aircraft originated.

Let us remember that the human factor investigator is the flight surgeon. This individual consults with his fellow board members, most of whom are rated aircrew, and with any authority he chooses. Typically, the board flight surgeon will call the safety agency to discuss his observations and speculations; experienced personnel will provide him with technical information, referral to other authorities and guidance in the further conduct of the investigation. The human factors investigator will also call the School of Aerospace Medicine at Brooks AFB in San Antonio and talk with individuals conducting research into acceleration effects, spatial disorientation, work/rest cycles and fatigue, heat stress, psychological stress (career, personal, familial), and vision, and he may call the Armstrong Laboratory at Wright Patterson AFB in Ohio to discuss other issues. Following his various consultations and approximately twenty days of investigation, the human factors investigator, the flight surgeon, completes a human factors protocol. I have presented an outline of this investigator's background and his method of inquiry to emphasize the fact that the validity of human factors data obtained depends on the experience and knowledge of the investigator. The validity of any conclusions we draw from these investigations depends on the quality of that data.

The protocol used by the human factors investigator is the revised Air Force Form 711gA which you will find in your documents package. This form has been in use since September of 1989 and is currently undergoing a second revision and a conversion to diskette format. This protocol then will be totally in computer format, and the investigator will work with either a laptop or desktop computer in completing the form.

In past years the protocol largely resulted in a great deal of data explaining what had occurred during the course of the aircraft accident but very little related to why the accident had occurred. The 1989 revision included data entries not previously captured, expands human factor categories, and for the first time provides a correlation matrix to be included by the investigator (see pg. 6 of the 711gA). We have known for many years that pilots "channelize" their attention during both actual and simulated combat and that a consequence of this narrow focus of attention is the exclusion of other information from the aircraft and the environment. This in turn leads to a loss of situational awareness and has resulted in many aircraft accidents. Student pilots learn of the hazards of channelized attention in the classroom and experience its effects during flight training. Most pilots have had fellow aviators who have suffered a crash, many of them fatal, and once again have learned of the dangers of "channelized attention". Throughout an aviator's career, he is periodically reminded of the various hazards inherent to the flying environment, including "channelized attention" and others such as spatial disorientation. We assume that this condition occurs as a result of the pilot's primary motivation to kill his opponent or drop his bomb on target and that he has suffered a major defect of judgement in not realizing the importance of his survival. But we do not really understand why an aviator can fly hundreds or thousands of hours safely and then on one fatal occasion, repeating a maneuver he has often accomplished successfully and safely, fails to maintain the situational awareness necessary for survival. We may say he was distracted by radio calls, or he did not sleep well the previous night or that he had a fight with his wife and his concentration in the cockpit was degraded. This pilot and many others have been exposed to these and other human factors and have not suffered an accident. Why this time? We often speculate but how often do we really know? The myriad of human factors included in the 711gA protocol, and most importantly, the correlation matrix, is an attempt to capture data that with appropriate analysis may give us a more complete understanding of the fatal mix of human factors, or a signature profile, that we can provide to commanders, supervisors, instructors and safety professionals.

Parallel with the use of the 711gA protocol by human factors investigators, the United States Air Force is developing a highly complex data encoding and analysis program, the "Aircraft Mishap Prevention" (AMP) program. AMP will provide statistical analysis capability for correlation and regression analyses and the development of an aircraft accident human factors signature profile. AMP consists of two IBM RISC 6000S, several 386 workstations for analyst personnel, and the necessary software to run the program. This program will become operational in 1995.

The human factors data from USAF "operations" aircraft accidents has been processed through a preliminary program we call "Mini-AMP". Let us look at what we have learned so far. Table I is a statistical summary of 57 operations (i.e. human factors) accidents. Table II provides a similar analysis of 38 logistical (system or mechanical failure) accidents. Note that although there are 371 possible human factors to be selected by the investigator that only 17 are selected with any frequency and that there is further reduction in the operations group to 6 with very frequent selection. It is probably no surprise to this audience that the major factors selected by our investigators are from the judgement and decision making group and the situational awareness group. It is quickly apparent that these frequently selected human factors are in the "what" category and not the "why". The "contributors" noted on Table I begin to provide some of the "why". As an example, note the third line of Table I, delay in taking necessary action and the second contributor, misperception of distance. One of the accidents this data related to was a fighter aircraft flying a defensive ACM exercise against another fighter. The accident occurred at 1600 H. Immediately prior to the engagement, the pilot of the chase aircraft had lifted his visor, high contrast yellow, but continued to wear his green sun glasses. He unknowingly experienced a "blue wash-out" effect, lost some depth perception, and was 800 meters closer to his adversary than he perceived. Although not the primary cause of this accident, this physiological event was a contributor and part of the complex chain leading to the accident.

You will also note the difference in the major human factor contributors between the operations (ops) group and the logistical (log) group. "Contributors" in the log group were either not reported or reported with little frequency.

This preliminary effort has provided us with the opportunity to recognize certain problems in human factor data gathering and analysis.

Our first concern is the quality of data reporting. The Untied States Air Force does not have a dedicated human factors aircraft accident investigator cadre. Although our human factor consultants at the Air Force Safety Agency (formerly called the Air Force Inspection and Safety Center) have been in the safety business for several years and have all been involved in working with numerous aircraft accidents, the front line investigator usually does one in an entire career. These human factor investigators, all Air Force flight surgeons, have experienced similar medical training and have all graduated from the USAF School of Aerospace Medicine Primary Course in Flight Medicine. However, they may serve on a safety investigation board after only two months or as much as three years service as a flight surgeon. Recognizing this problem, the Air Force plans to initiate a course in aircraft accident investigation for human factor investigators (to include flight surgeons, physiologists, and aviation psychologists), two weeks in duration at the USAF School of aerospace medicine at Brooks AFB. Graduates of this course will constitute a cadre of specially trained professionals who will be consistently required to serve as safety investigation board human factor investigators. This course is planned to begin in the Fall of 1993.

Another concern is the specific nature or type of data required that will eventually answer the question of why human factor accidents occur and provide useful information for the prevention of future accidents. Although the 711gA protocol is very detailed, it is the first attempt in concert with the AMP program and will certainly require further revision and elaboration. The quantity of data required to distinguish between aviators who have aircraft accidents and those who do not is another concern. Our statisticians say that at least five years of aircraft accident data, with a comparison cohort group, will need to be analyzed.

It is likely that the human factor causes of aircraft accidents do not vary greatly from country to country and that we share many of the same problems of human error. I would propose to this group that we construct a universal human factors protocol, and that our investigators be trained in the same program. Initially, I suggest the 711gA protocol be reviewed and modified by NATO safety organizations for joint use and that our human factors investigators be jointly trained at the USAF School of Aerospace Medicine.

In summary, we lose many aircraft and aviators due to human factor causes we incompletely understand. We are no longer satisfied with the simplistic concept of pilot error and have come to realize that human factor caused accidents are very complex events that require very careful investigation and analysis. I have proposed a method of investigation and analysis that we share as a joint endeavor.

TABLE I

OPS MISHAPS

106 CLASS A/A+ MISHAPS (57 OPS, 38 LOG, 7 OTHER, 4 UNKNOWN)
(719 3s & 4S; 156 4s RANKED 1/2; 124 4s RANKED 1/2 FOR PILOTS (69) ONLY

HUMAN FACTOR	INCIDENCE of 3s & 4s	TIMES RATED #1 OR #2	RATED #1/#2 (PILOTS)	CONTRIBUTORS
CHANNELIZED ATTENTION	1 (34)	2 (11)	2 (8)	COGNIT TSK OVERSAT (2) LIMITED TOT EXPER (2)
SEL WRNG CRSE OF ACTION	2 (29)	3 (10)	1 (10)	RISK ASSESSMENT (3) COG TSK SAT (2) CONFUSN (2)
DELAY IN TKNG NESS ACTION	3 (23)	7 (6)	6 (5)	RISK ASSESSMENT (2) MSPRCPTN OF DISTNCE (2)
RISK ASSESSMENT	4 (21)	8 (5)	8 (4)	SEL WNG CRSE ACT (3) DISTRACTION (3)
FAIL TO USE ACPT PROCEDS	4 (21)	6 (7)	4 (7)	NO TREND
SDO, TYPE I	6 (20)	1 (13)	2 (8)	VESTIBULAR ILLUSN (4) CHANNELIZED ATTN (3)
MISPERCEPTION OF POSITION	7 (19)	10 (4)	13 (2)	
DISTRACTION	8 (18)	12 (3)	10 (3)	
VIOLATION FLT DISCIPLN	9 (15)	4 (9)	4 (7)	RISK ASSESSMENT (3) FAIL TO USE PROC/SEL WNG CRS (2)
INADEQUATE OPS BRIEFING	10 (12)	4 (9)	10 (3)	
VESTIBULAR ILLUSION	11 (10)	0	0	
INADEQT WRTTN OPS PROCDS	11 (10)	(1)	(1)	
COGNITIVE TASK OVERSAT	11 (10)	(2)	(2)	
SITUATNL AWARENESS-OTHER	11 (10)	(1)	(1)	
INADEQUATE SUPERVISION	11 (10)	12 (3)	13 (2)	
COMPLACENCY	16 (9)	(2)	(2)	
JUDGMENT/DECSNS, OTHER	20 (8)	8 (5)	6 (5)	CHANNELIZED ATTN (2)

TABLE II

LOG/MISC/UNK MISHAPS

106 CLASS A/A+ MISHAPS (57 OPS, 38 LOG, 7 OTHER, 4 UNKNOWN)
(393 3s & 4S; 69 4s RANKED 1/2; 31 4s RANKED 1/2 FOR PILOTS (31) ONLY

HUMAN FACTOR	INCIDENCE of 3s & 4s	TIMES RATED #1 OR #2	RATED #1/#2 (PILOTS)	CONTRIBUTORS
CREW COORDINATION	1 (11)	7 (3)	(1)	
FAIL TO USE ACPT PROCEDS	1 (11)	3 (4)	2 (3)	
INADQ WRITTEN OPS PROCEDS	3 (9)	2 (5)	1 (4)	
LOG/MNX PROCEDURES	4 (8)	1 (7)	4 (2)	
ACCELERTN/DECELRATN FRCES	4 (8)	(2)	(1)	
INADEQTE LOG/MNX INSPECTN	6 (7)	(2)	(0)	
INADEQUATE MNX TECH DATA	6 (7)	3 (4)	2 (3)	
OTHER AIRFLD CAPABILITIES	6 (7)	(2)	(1)	
CHANNELIZED ATTENTION	8 (6)	(0)	(0)	
OVERCONFIDENCE	8 (6)	(1)	(0)	
LOG/MNX SUPERVISION	8 (6)	7 (3)	(0)	
TIME INTO CREW DUTY DAY	8 (6)	(0)	(0)	
UNIT MISSION DEMANDS	8 (6)	(0)	(0)	
INTRACOCKPIT COMM	8 (6)	3 (4)	4 (2)	
SEAT DESIGN	8 (6)	(2)	(0)	
DELAY IN TAK NESS ACTN	15 (5)	7 (3)	(0)	
TECHNC/PROCEDURL KNOWLDG	15 (5)	(0)	(0)	

Appendix 1 - Human Factors Protocol

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LIFE SCIENCES REPORT OF AN INDIVIDUAL INVOLVED IN AN AIR FORCE FLIGHT/FLIGHT RELATED MISHAP

GENERAL INSTRUCTIONS: COMPLETE ONE FORM FOR EACH INDIVIDUAL IAW AFR 127-4. ENTER ANSWERS BY HAND PRINTING OR TYPING. ATTACH THE LIFE SCIENCE NARRATIVE AT THE END OF THE FORM. IF MORE THAN ONE INDIVIDUAL IS INVOLVED IN THE MISHAP, A SINGLE NARRATIVE IS ACCEPTABLE PROVIDED EACH PERSON HAS THEIR OWN SECTION FOR INJURIES AND THE 72 HOUR HISTORY. ATTACH THE LATEST TWO (2) PHYSICALS, INCLUDING THE MOST RECENT SF - 88, ONLY TO HQ AFISC / SER.

PRIVACY ACT STATEMENT

AUTHORITY: 10 USC 8012

PRINCIPAL PURPOSE(S): Investigations of mishaps are conducted for mishap prevention purposes within the Air Force.

ROUTINE USES: To provide statistical and historical information used by the Department of Defense for mishap prevention. Specifically, for special studies involving egress, ejection, search, rescue, survival, related equipment or training, physiological, medical or injury data. When data are used for safety educational or promotional materials, the identities of involved personnel are not disclosed.

DISCLOSURE IS MANDATORY: Unless the individual is suspected of committing a violation of the Uniform Code of Military Justice. This information is needed to ensure your personal safety and that of others.

1. INDIVIDUAL BACKGROUND

a. IDENTIFICATION

(1) NAME: ____________ (First / Middle / Last)
(2) SSAN: ____________
(3) RANK: ____________
(4) SEX: (male/female): ____________
(5) DOB: (yy / mm / dd): ____________
(6) CREW POSITION: (AFSC) ____________
(7) DATE OF MISHAP (yymmdd): ____________
(8) ASSIGNED UNIT: ____________
(9) ASSIGNED BASE: ____________
(10) BASE NEAREST MISHAP: ____________
(11) COMMAND: ____________
(12) AIRCRAFT MDS: ____________
(13) AERO RATING: ____________
(14) SOURCE OF COMMISSION: ____________ *(OTS, USAFA, ROTC, OTHER)*
(15) Was this person in control of the aircraft (hands on controls) at the time of, or during, the mishap?
Yes ____ No ____ Unknown ____
(16) MARITAL STATUS: Single _____ Married _____ Separated _____ Divorced _____

b. MEDICAL HISTORY

(1) ANTHROPOMETRY **Use inches and pounds**

(a) HEIGHT: _______ (b) WEIGHT: _______
(c) HAND DOMINANCE: Right ______; Left ______; Ambidextrous ______

Complete (d) - (f) if available.
(d) BUTTOCK KNEE LENGTH: ________
(e) LEG LENGTH: ________
(f) FUNCTIONAL REACH: ________
(g) SITTING HEIGHT: ________

(2) VISION **Indicate Y- Yes, N- No, or U- Unknown**
(a) Corrected ________
(b) Multifocal ________
(c) Contacts ________
(d) Used ________
(e) Current ________
(f) Sunglasses worn during mishap ________

(3) TOBACCO **Indicate Y- Yes, N- No, or U- Unknown**
(a) Smoke ______ (d) Cigarette packs/day ______
(b) Sniff ______ (e) Pipe bowls/day ______
(c) Chew / Dip ______ (f) Cigars/day ______

(4) PRE-EXISTING DISEASE(S) / ILLNESS

(a) DIAGNOSES	(b) WAIVER YES/NO DATE	(c) USAFSAM YES/NO DATE

Attach additional pages if needed

(5) Are latest two physicals attached? Yes ___ No ___.
(ATTACH TO HQ AFISC COPY ONLY)

(6) Date of last flight physical: ____________

c. WORK / REST HISTORY Time in hours and tenths

(1) Hours worked in last 24 hrs. ____________
(2) Hours worked in last 48 hrs. ____________
(3) Hours worked in last 72 hrs. ____________
(4) Continuous time awake prior to mishap. ____________
(5) Hours slept in last 24 hrs. ____________
(6) Hours slept in last 48 hrs. ____________
(7) Hours slept in last 72 hrs. ____________
(8) Duration of last sleep period. ____________
(9) Hours between last meal and mishap. ____________

2. MISHAP MEDICAL INFORMATION

a. OVERALL DEGREE OF INJURY

(1) NONE ________
(2) MINOR ________
(3) MAJOR ________
(4) FATAL ________
(5) MISSING ________

MARK ONLY ONE

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

711gA INJURY LOCATIONS, DIAGNOSIS, AND CAUSE CODES

BODY PART

A	ANTERIOR
S	BILATERAL
E	ENTIRE BODY
L	LEFT
M	MEDIAL
P	POSTERIOR
R	RIGHT
U	UNKNOWN

BODY LOCATION

B01	ABDOMEN
B02	ANKLE
B03	ARM LOWER
B04	ARM UPPER
B05	BACK(NONFRACTURE)
B06	BASAL SKULL
B07	BRACHIAL PLEXUS.
B08	BRAIN
B09	BUTTOCKS
B10	CHIN
B11	CLAVICLE
BC1	C1
BC2	C2
BC3	C3
BC4	C4
BC5	C5
BC6	C6
BC7	C7
B12	EAR
B13	ELBOW
B14	ENTIRE BODY
B15	EYE
B16	FACE
B17	FACIAL BONES
B18	FEMUR
B19	FIBULA
B20	FINGER
B21	FOOT
B22	GREAT VESSELS
B23	HAND
B24	HEAD
B25	HEART
B26	HIP
B27	HUMERUS
B28	INGUINAL
B29	JAW
B30	KIDNEY
B31	KNEE
B32	LEG LOWER
B33	LEG UPPER
B34	LIVER
B35	LUNG
BL1	L1
BL2	L2
BL3	L3
BL4	L4
BL5	L5
B36	MENINGES
B37	MULT BODY PARTS
B38	MULTIPLE EXTREME
B39	NECK
B40	NOSE
B41	PELVIS
B42	PUBIC
B43	RADIUS
B44	RIBS
B45	SACROILLIAC
B46	SACRUM COCCYX
B47	SCAPULA
B48	SHOULDER
B49	SKULL
B50	SPINAL CORD
B51	SPLEEN
B52	STERNUM
B53	THORAX
B54	THUMB
B55	TIBIA
B56	TIBIA & FIBULA
B57	TOES
BT1	T1
BT2	T2
BT3	T3
BT4	T4
BT5	T5
BT6	T6
BT7	T7
BT8	T8
BT9	T9
BTA	T10
BTB	T11
BTC	T12
B58	ULNA
B59	ULNA & RADIUS
B60	UNKNOWN FRACTURE
B61	UNKNOWN/NA
B62	WRIST
B63	10%BODY SURFACE
B64	20%BODY SURFACE
B65	30%BODY SURFACE
B66	40%BODY SURFACE
B67	50%BODY SURFACE
B68	60%BODY SURFACE
B69	70%BODY SURFACE
B70	80%BODY SURFACE
B71	90%BODY SURFACE

DIAGNOSIS

D01	ABRASION
D02	ACOUSTIC TRAMA
D03	AMPUTATION
D04	ASPHYXIA
D05	ASPHYXIA-TOXIC
D06	AVULSION
D07	BITE-ANIMAL
D08	BITE-HUMAN
D09	BLAST INJURY
D10	BLUNT TRAMA
D11	BURN-1ST DEGREE
D12	BURN-2ND DEGREE
D13	BURN-3RD DEGREE
D14	BURN-4TH DEGREE
D15	BURN-CHEMICAL
D16	BURN-ELECTRICAL
D17	CONCUSSION
D18	CONTUSION
D19	CRUSH INJURY
D20	DCS (BENDS)
D21	DCS (CHOKE)
D22	DCS (CNS)
D23	DCS (CRAWLS)
D24	DECAPITATION
D25	DEHYDRATION
D26	DEPRESSED
D27	DISLOCATION
D28	DROWNING
D29	EDEMA
D30	ELECTROCUTION
D31	EMBOLISM
D32	EVISCERATION
D33	EXHAUSTION
D34	EXSANGUINATION
D35	FOREIGN BODY
D36	FRACTURE DISLOCATION
D37	FRAGMENTATION
D38	FROSTBITE
D39	FX, ANT COMP W/CORD INJURY
D40	FX, ANT COMPRESSION
D41	FX, COMMIUTED
D42	FX, COMPOUND
D43	FX, HYPEREXTEN W/CORD INJURY
D44	FX, HYPEREXTENSION
D45	FX, IMPACTED
D46	FX, SIMPLE
D47	FX, UNIFORM COMP
D48	FX, UNIFORM COMP W/CORD INJURY
D49	FXS, MULTIPLE
D50	GUNSHOT WOUND
D51	HEAT EXHAUSTION
D52	HEAT STROKE
D53	HEMARTHROSIS
D54	HEMATOMA
D55	HEMIPLEGIA
D56	HEMORRHAGE (W/ SHOCK)
D57	HEMORRHAGE
D58	HERNIA
D59	HYPOTHERMIA
D60	IMMERSION INJURY
D61	INFARCT
D62	INTERNAL DERANGEMENT
D63	LACERATION
D64	LOST
D65	MULTIPLE EXTREME INJURIES
D66	OTHER INJURY
D67	OTHER OCCUPATIONAL DISEASE
D68	PARAPLEGIA
D69	PARESIS
D70	PNEUMOTHORAX
D71	PUNCTURE
D72	QUADRIPLEGIA
D73	RAD INJURY IONIZING
D74	RAD INJURY NONIONIZING
D75	RUPTURE
D76	SEVERED NERVES
D77	SPRAIN/STRAIN
D78	STAB WOUND
D79	STARVATION
D80	STRETCHING
D81	TEAR
D82	TOXIC REACTION
D83	TOXIC REACTION SKIN
D84	TOXIC REACTION SYSTEMIC
D85	TRANSECTION
D86	TRAPED GAS EAR BLOCK
D87	TRAPPED GAS ABDOMINAL
D88	TRAPPED GAS DENTAL
D89	TRAPPED GAS SINUS BLOCK
D90	UNCONSCIOUNESS
D91	UNKNOWN/NA

CAUSE OF INJURY

C01	BIRD STRIKE
C02	BLAST / EXPLOSION / DISINTEGRATION
C03	BORANES
C04	BULLET WOUNDS
C05	CB (FIRE EXTINGUISHENT)
C06	COLD
C07	DEBARKING ACFT ON GND
C08	DECELERATION, LONGITUDINAL
C09	DECELERATION, VERTICAL
C10	DEFORMATION OF ACFT
C11	DRAGGING
C12	DROWNING
C13	DUSTS
C14	EJECTION FORCE
C15	EJECTION THRU CANOPY
C16	ENTANGLE (EQPT/CHUTE)
C17	ENTANGLE SHROUD LINE WATER
C18	ESCAPE ROPE
C19	EXPLOSION
C20	EXPLOSIVE DECOMPRESSION
C21	FAILURE OF SURVIVAL EQUIPMENT
C22	FIRE
C23	FIREBALL
C24	FUELS(GASOLINE ETC)
C25	FUMES/SMOKE
C26	G FORCES
C27	GASES
C28	HEAT
C29	HIT BY DEBRIS ACFT
C30	HYDRAULIC FLUIDS
C31	HYPOXIA
C32	INITIAL IMPACT W/ TERRAIN
C33	JET BLAST/PROP WASH
C34	LACK OF SURVIVAL EQUIPMENT
C35	LANDED ON SURVIVAL KIT
C36	MISSING
C37	MISTS
C38	MISUSE OF SURVIVAL EQUIPMENT
C39	NITROGEN OXIDES
C40	OBJECT DISLODGED/DROP IN / DURING FLIGHT
C41	OPENING SHOCK OF CHUTE
C42	POOR PLF
C43	RESTRAINT(S)
C44	ROCKET BLAST
C45	SEAT COLLAPSE
C46	SECONDARY IMPACT W/ TERRAIN
C47	SHRAPNEL
C48	SOLVENTS
C49	STRUCK BY DISLODGED EQPT
C50	STRUCK BY EJECTION SEAT
C51	STRUCK BY MOVING ACFT
C52	STRUCK BY OTHER ACFT
C53	STRUCK BY OTHER INDIV
C54	STRUCK BY PERSONAL EQPT
C55	STRUCK BY ROTOR BLADE/ PROP
C56	STRUCK BY UNATTACHED EQUIPMENT
C57	STRUCK CABIN STRUCTURE
C58	STRUCK CANOPY
C59	STRUCK CTL STICK
C60	STRUCK ESCAPE HATCH
C61	STRUCK EXTL SURF ACFT
C62	STRUCK GUN SIGHT (HUD)
C63	STRUCK OTHER COCKPIT STRUCTURE
C64	STRUCK RADARSCOPE
C65	STRUCK WINDSHIELD
C66	SUCKED INTO JET INTAKE
C67	THROWN OUT OF ACFT
C68	TRAPPED
C69	TUMBLING
C70	TURBULENCE
C71	UDMH-HYDRAZINE
C72	UNKNOWN
C73	WINDBLAST

EXAMPLE	Injury code
INJURY / DIAGNOSIS: Left upper arm fracture compound	L, B04, D42
CAUSE: Broken on ejection due to wind blast	C73

INSERT TO AF FORM 711gA Aug 89

b. LABORATORY TESTS: (Blood and body fluids.)

(1) TYPE TEST	(2) TISSUE TESTED	(3) TESTING LAB	(4) METHOD	(5) RESULT

NOTE: FOR MORE TESTS, DISEASES, INJURIES, OR RESULTS, INCLUDE THEM ON PLAIN BOND CONTINUATION SHEET(S).

c. INJURIES (body part/injury): For non-survivable impact forces indicate MULTIPLE EXTREME or TOTAL FRAGMENTATION when applicable. *LIST INJURIES IN DECREASING ORDER OF SEVERITY*	INJURY CODE SEE FACING PAGE
(1) INJURY / DIAGNOSIS:	
CAUSE:	
(2) INJURY / DIAGNOSIS:	
CAUSE:	
(3) INJURY / DIAGNOSIS:	
CAUSE:	
(4) INJURY / DIAGNOSIS:	
CAUSE:	
(5) INJURY / DIAGNOSIS:	
CAUSE:	
(6) INJURY / DIAGNOSIS:	
CAUSE:	

CAUSE EXAMPLES Bird Strike, Burn (chemical, fuel), Drowning, Parachute Landing Fall(PLF), Ejection, Explosion, Flail, Impact with ..?, Personal Equipment. Generally give the WHAT and HOW of the injury cause and WHEN it was sustained.

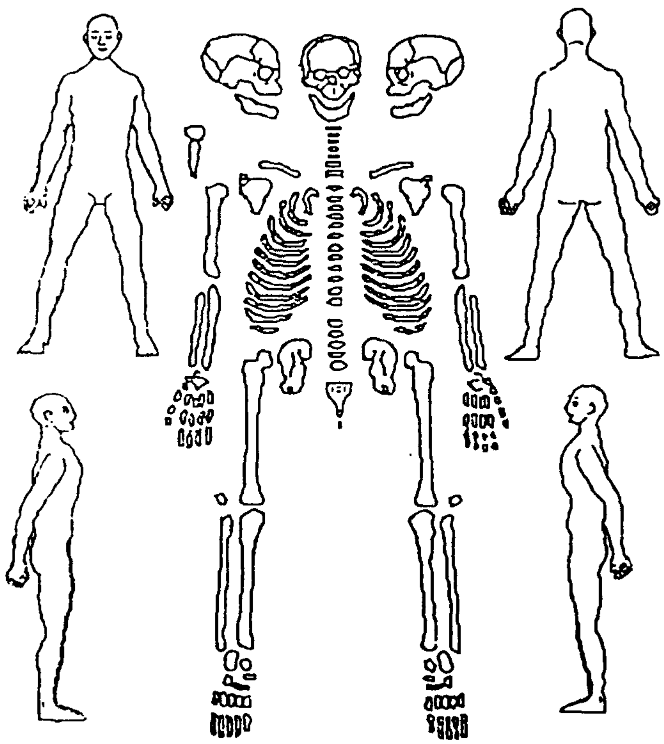
d. X-RAY RESULTS

(1) AREA / LOCATION (2) FINDINGS

e. INJURY INCAPACITATION TIMES

Indicate time or "N/A."

(1) DAYS HOSPITALIZED ________
(2) DAYS IN QUARTERS ________
(3) DAYS GROUNDED (DNIF) ______
(4) TIME OF UNCONSCIOUSNESS
(a) (hrs/mins) ________
(b) (seconds) ________



INJURY PROFILE (MARK OR DRAW INJURIES WHEN APPLICABLE)

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

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Evaluate each factor for **presence** and the **significance** of its contribution. Mark **PRESENT** Factors with either **0, 1, 2, 3, or 4** from contribution scale. If Factor **NOT PRESENT** leave blank, if **UNKNOWN** if factor PRESENT mark with **"U"**.

NONE 0 — 1 — 2 — 3 — 4 DEFINITE

DISCUSS PRESENT FACTORS IN THE HUMAN FACTORS PORTION OF THE NARRATIVE

3. HUMAN PERFORMANCE AND ENVIRONMENTAL CONCERNS

INDIVIDUAL FACTORS

A PHYSIOLOGIC OR BIODYNAMIC FACTORS

1 BIODYNAMIC

101___ HYPOXIA
102___ HYPERVENTILATION
103___ EAR BLOCK
104___ ALTERNOBARIC VERTIGO
105___ SINUS BLOCK
106___ BARODONTALGIA
107___ PNEUMOTHORAX
108___ ABDOMINAL GAS
109___ BENDS/DECOMPRESSION SICKNESS
110___ CHOKES/DECOMPRESSION SICKNESS
111___ CNS/DECOMPRESSION SICKNESS
112___ G-INDUCED VISION DEFICIT
113___ G-INDUCED LOSS OF CONSCIOUSNESS
114___ OTHER___________

2 SENSORY AND PERCEPTUAL

115___ VISION DEFICIT
116___ VISUAL ACQUISITION
117___ VISUAL ILLUSION
118___ VESTIBULAR ILLUSION
119___ KINESTHETIC ILLUSION
120___ AUDITORY CUES
121___ NOISE INTERFERENCE
122___ VIBRATION
123___ MISPERCEPTION OF SPEED
124___ MISPERCEPTION OF DISTANCE
125___ MISPERCEPTION OF POSITION
126___ SPATIAL DISORIENTATION (TYPE 1) UNRECOGNIZED
127___ SPATIAL DISORIENTATION (TYPE 2) RECOGNIZED
128___ SPATIAL DISORIENTATION (TYPE 3) UNCONTROLLABLE
129___ OTHER___________

3 PATHOPHYSIOLOGICAL

130___ DRUGS PRESCRIBED BY MEDICAL OFFICER
131___ DRUGS, OTHER
132___ SIDE EFFECTS / HANGOVER
133___ ALCOHOL
134___ NICOTINE
135___ CAFFEINE
136___ NUTRITION
137___ DEHYDRATION
138___ WAIVERS, MEDICAL
139___ PHYSICAL FITNESS
140___ PHYSICAL FATIGUE
141___ SUDDEN INCAPACITATION / UNCONSCIOUSNESS
142___ FOOD POISONING
143___ CARBON MONOXIDE POISONING
144___ TOXIC EXPOSURE
145___ MOTION SICKNESS
146___ OTHER ACUTE ILLNESS
147___ OTHER PRE-EXISTING DISEASE/DEFECT
148___ THERMAL STRESS HEAT
149___ THERMAL STRESS COLD
150___ RADIATION
151___ OTHER___________

4 ANTHROPOMETRIC

152___ WORKSPACE INCOMPATIBLE WITH HUMAN
153___ INADVERTENT OPERATION, MECHANICALLY INDUCED
154___ BODY SIZE
155___ PHYSICAL STRENGTH
156___ PHYSICAL MOBILITY
157___ DEXTERITY
158___ OTHER___________

B PSYCHOLOGICAL FACTORS

1 PROFICIENCY

159___ INADEQUATE TRANSITION
160___ LIMITED TOTAL EXPERIENCE
161___ LIMITED RECENT EXPERIENCE
162___ NEGATIVE TRANSFER
163___ USED WRONG CONTROL
164___ EVENT PROFICIENCY
165___ EVENT CURRENCY
166___ JOB / FLYING PROFICIENCY
167___ JOB / FLYING CURRENCY
168___ LEARNING ABILITY, RATE
169___ MEMORY ABILITY
170___ TECHNICAL / PROCEDURAL KNOWLEDGE
171___ OTHER___________

2 SITUATIONAL AWARENESS

172___ INATTENTION
173___ SELECTIVE INATTENTION
174___ CHANNELIZED ATTENTION
175___ DISTRACTION
176___ BOREDOM
177___ FASCINATION
178___ TEMPORAL DISTORTION
179___ CONFUSION
180___ COGNITIVE TASK OVERSATURATION
181___ HABIT INTERFERENCE
182___ MISREAD INSTRUMENTS
183___ MISINTERPRETED INSTRUMENT READING
184___ OTHER___________

3 MENTAL FATIGUE

185___ ACUTE
186___ CHRONIC
187___ MOTIVATIONAL EXHAUSTION (BURNOUT)
188___ SLEEP DEPRIVATION
189___ CIRCADIAN RHYTHM DESYNCHRONY
190___ OTHER___________

4 PERCEPTUAL-MOTOR CAPABILITIES

191___ PHYSICAL TASK OVERSATURATION
192___ TIME AND SPACE LIMITATION
193___ CONFUSION OF CONTROLS
194___ INADEQUATE COORDINATION OR TIMING
195___ FLYING SKILL ABILITY / DEFICIENCY
196___ OVERCONTROL
197___ OTHER___________

5 JUDGMENT AND DECISION MAKING

198___ FAILURE TO USE ACCEPTED PROCEDURES
199___ SELECTED WRONG COURSE OF ACTION
200___ DELAY IN TAKING NECESSARY ACTION
201___ RUSH IN TAKING NECESSARY ACTION
202___ VIOLATION OF FLIGHT DISCIPLINE
203___ PROCEDURE / NAVIGATIONAL ERROR
204___ INADVERTENT OPERATION, SELF-INDUCED
205___ GET-HOME-ITIS / GET-THERE-ITIS
206___ RISK ASSESSMENT
207___ IGNORED CAUTION / WARNING
208___ OTHER___________

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

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NONE 0 — 1 — 2 — 3 — 4 DEFINITE

DISCUSS PRESENT FACTORS IN THE HUMAN FACTORS PORTION OF THE NARRATIVE

6 PERSONALITY INFLUENCES

(a) EMOTIONAL STATE

209___ APPREHENSION
210___ PANIC / CHOKE / FREEZE
211___ ANGER
212___ DEPRESSION
213___ RECENT CHANGE
214___ IRRITABLE
215___ CAREFREE
216___ ELATION
217___ UNKNOWN
218___ OTHER___

(b) BEHAVIOR

219___ RESPONSE SET
220___ PRESSING
221___ PREOCCUPATION
222___ EXCESSIVE MOTIVATION TO SUCCEED
223___ LACK OF DISCIPLINE
224___ LACK OF CONFIDENCE
225___ OVERCONFIDENCE
226___ OVERCOMMITMENT
227___ MOTIVATION MISPLACED
228___ MOTIVATION INADEQUATE
229___ GAMESMANSHIP OR CAREERISM
230___ OVERAGGRESSIVE
231___ COMPLACENCY
232___ OTHER___

(c) PERSONALITY STYLE

233___ NARCISSISTIC
234___ EXPLOSIVE
235___ IMPULSIVE
236___ INVULNERABLE
237___ MACHO
238___ PASSIVE AGGRESSIVE
239___ SUBMISSIVE
240___ CONSERVATIVE
241___ LONER
242___ AUTHORITARIAN
243___ NONE OF THE ABOVE
244___ OTHER___

C PSYCHOSOCIAL FACTORS

1 PEER INFLUENCES

245___ PEER PRESSURE, EXPRESSED
246___ PEER PERCEPTION/MORALE
247___ PEER OR CREW RULE VIOLATIONS
248___ OFFICERSHIP
249___ REPUTATION
250___ OTHER___

2 PERSONAL AND COMMUNITY

251___ CAREER / JOB PROGRESSION
252___ CAREER / JOB SATISFACTION
253___ RECENT OR PLANNED CHANGE IN CAREER / JOB
254___ INTERPERSONAL RELATIONSHIPS
255___ FAMILY OR FRIEND DEATH/ILLNESS
256___ FINANCIAL PROBLEMS
257___ LEGAL PROBLEMS
258___ MARITAL PROBLEMS
259___ FAMILY PROBLEMS
260___ RECENT HOLIDAY/VACATION
261___ RECENT PROMOTION CONSIDERATION
262___ RECENT ENGAGEMENT / MARRIAGE
263___ RECENT DIVORCE / SEPARATION
264___ COMMUNITY ACTIVITY PARTICIPATION
265___ EDUCATION BACKGROUND
266___ OTHER___

3 COMMUNICATION

267___ MISINTERPRETED COMMUNICATIONS
268___ DISRUPTED COMMUNICATIONS
269___ COMMUNICATION HABITS
270___ CREW COORDINATION
271___ EXTERNAL COMMUNICATION
272___ INADEQUATE COMMUNICATION EQUIPMENT
273___ INTRACOCKPIT COMMUNICATION
274___ BLOCKED TRANSMISSION
275___ RADIO DISCIPLINE
276___ OTHER___

ENVIRONMENTAL FACTORS

A AIRCRAFT / COCKPIT DESIGN FACTORS

1 COCKPIT SEAT

277___ ACCELERATION OR DECELERATION FORCES, IMPACT
278___ SEAT DESIGN
279___ SEAT COMFORT
280___ FIXED SEAT RESTRAINT
281___ LIMB RESTRAINT
282___ EJECTION SEAT SEQUENCING
283___ OTHER___

2 VISIBILITY

284___ VISION RESTRICTED BY EQUIPMENT STRUCTURES
285___ COCKPIT LIGHTING
286___ GLARE
287___ CANOPY REFLECTIONS
288___ CANOPY DESIGN
289___ HEAD-UP-DISPLAY DESIGN - LOCATION
290___ HEAD-UP-DISPLAY DESIGN - SYMBOLOGY
291___ OTHER___

3 INSTRUMENTATION

292___ DESIGN
293___ SIZE
294___ LIGHTING
295___ SYMBOLOGY
296___ FAILURE
297___ LOCATION
298___ MISLED BY FAULTY INSTRUMENT
299___ OTHER___

4 CONTROLS

300___ DESIGN
301___ SIZE
302___ LIGHTING
303___ FAILURE
304___ SWITCH LOCATION
305___ SWITCH SIZE
306___ SWITCH SHAPE
307___ LOCATION
308___ OTHER___

5 AUTOMATION

309___ FUNCTIONAL DESIGN OF SYSTEM
310___ USE POLICY
311___ EMPLOYMENT GUIDANCE
312___ FUNCTIONAL DEFICIENCY
313___ SYMBOLOGY
314___ FAILURE STATUS INDICATOR
315___ MANUAL BACKUP INADEQUATE
316___ RELIABILITY
317___ PROGRAM LOGIC
318___ DESIGN DEFICIENCY
319___ OTHER___

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

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Evaluate each factor for **presence** and the **significance** of its contribution. Mark **PRESENT** Factors with either **0, 1, 2, 3, or 4** from contribution scale. If Factor **NOT PRESENT** leave blank, if **UNKNOWN** if factor PRESENT mark with **"U"**.

NONE 0 — 1 — 2 — 3 — 4 DEFINITE

DISCUSS PRESENT FACTORS IN THE HUMAN FACTORS PORTION OF THE NARRATIVE

B OPERATIONS FACTORS

1 PREPARATION
320___ INADEQUATE BRIEFING
321___ SYSTEMS KNOWLEDGE (DASH 1)
322___ FAULTY FLIGHT PLAN
323___ FAULTY PRE-FLIGHT OF AIRCRAFT
324___ INADEQUATE WEATHER ANALYSIS
325___ OTHER___

2 COCKPIT RESOURCE MANAGEMENT / CREW COORDINATION
326___ INITIAL FORMAL TRAINING
327___ RECURRENT TRAINING
328___ LEADERSHIP (COMMANDER STYLE)
329___ SUBORDINATE STYLE / COPILOT SYNDROME
330___ DEFACTO - POLICY
331___ RANK IMBALANCE
332___ OTHER___

3 PROCEDURAL GUIDANCE / PUBLICATIONS
333___ INADEQUATE WRITTEN PROCEDURES
334___ INAPPROPRIATE WRITTEN PROCEDURES
335___ INADEQUATE GRAPHIC DEPICTION
336___ MISLEADING GUIDANCE
337___ NOT CURRENT
338___ OTHER___

4 MISSION DEMANDS
339___ HURRIED / DELAYED DEPARTURE
340___ CREW / FLIGHT MAKEUP / COMPOSITION
341___ ACCELERATION FORCES, IN-FLIGHT
342___ LOSS OF AIRCRAFT PRESSURIZATION
343___ LIGHTING OF OTHER AIRCRAFT
344___ VISION RESTRICTED BY WEATHER, HAZE, DARKNESS
345___ VISION RESTRICTED BY ICING, WINDOWS FOGGED, ETC.
346___ VISION RESTRICTED BY DUST, SMOKE, ETC. IN AIRCRAFT
347___ WEATHER, OTHER THAN VISIBILITY RESTRICTION
348___ EXERCISES / EVALUATIONS
349___ NUMEROUS TDY'S
350___ UNIT MISSION DEMANDS
351___ CREW REST
352___ TIME INTO CREW DUTY DAY
353___ SUPERVISORY PRESSURES
354___ INTERNALIZED UNIT / ORGANIZATIONAL VALUES
355___ RULES CONFORMANCE
356___ OTHER___

C FACILITIES AND SERVICES FACTORS

1 AIRCREW SUPPORT
357___ ACCESS TO DINING FACILITIES
358___ RESIDENCE QUARTERS
359___ CREW REST QUARTERS
360___ ACCESS TO EXERCISE
361___ ACCESS TO RECREATION OR LEAVE
362___ MEDICAL CARE
363___ TRANSIENT MAINTENANCE
364___ DUTY LOCATION SATISFACTION
365___ OTHER___

2 AIR TRAFFIC CONTROL
366___ LANGUAGE BARRIER
367___ INAPPROPRIATE GUIDANCE
368___ INACCURATE GUIDANCE
369___ LACK OF NAV-AIDS / ENROUTE
370___ INADEQUATE MONITORING
371___ OTHER___

3 AIRFIELD CAPABILITIES
372___ RUNWAY LIGHTING
373___ RUNWAY DIMENSIONS
374___ RUNWAY SLOPE
375___ SURROUNDING ENVIRONMENT
376___ LACK OF NAV-AIDS / RADAR
377___ INADEQUATE MONITORING
378___ OTHER___

D EQUIPMENT FACTORS

1 LOGISTICS/MAINTENANCE PERSONNEL
379___ INADEQUATE INSPECTION
380___ INADEQUATE INSPECTION POLICY
381___ SUPERVISION
382___ COMMAND GUIDANCE
383___ PROCEDURES
384___ DESIGN
385___ OTHER___

2 LOGISTICS/MAINTENANCE QUALITY ASSURANCE
386___ INADEQUATE INSPECTION
387___ INADEQUATE INSPECTION POLICY
388___ SUPERVISION
389___ PROCEDURES
390___ OTHER___

3 LOCAL WORKING CONDITIONS
391___ MANNING
392___ TRAINING
393___ PERSONNEL HARMONY
394___ PHYSICAL PLANT
395___ SUPERVISION
396___ OTHER___

4 LOGISTICS/MAINTENANCE MANAGEMENT
397___ OVERHAUL POLICIES
398___ ACQUISITION POLICIES
399___ MODIFICATION POLICIES
400___ ATTRITION POLICIES
401___ OTHER___

5 PUBLICATIONS / PROCEDURAL GUIDANCE
402___ INADEQUATE TECHNICAL DATA
403___ INADEQUATE WRITTEN PROCEDURES
404___ INADEQUATE/MISLEADING REGULATIONS
405___ INADEQUATE GRAPHIC DEPICTION
406___ NOT CURRENT
407___ OTHER___

E INSTITUTIONAL OR MANAGEMENT FACTORS

1 SUPERVISORY INFLUENCES
408___ AVAILABILITY
409___ INADEQUATE
410___ PERSONALITY CONFLICT
411___ COMMAND AND CONTROL
412___ MODELING (IMITATIVE LEARNING)
413___ DISCIPLINE ENFORCEMENT
414___ SENSITIVE TO PRESSURE
415___ COMPETENCY
416___ LACK OF FEEDBACK
417___ ORDERED/LED ON FLIGHT BEYOND CAPABILITY
418___ OTHER___

2 INDICATE LEVEL OF SUPERVISORY FACTOR (E.1)
419___ SUPERVISOR OF FLYING
420___ FLIGHT
421___ SQUADRON
422___ WING
423___ GROUP
424___ AIR DIVISION
425___ NUMBERED AIR FORCE
426___ MAJOR COMMAND
427___ AIR FORCE
428___ OTHER___

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

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NONE 0 — 1 — 2 — 3 — 4 DEFINITE

DISCUSS PRESENT FACTORS IN THE HUMAN FACTORS PORTION OF THE NARRATIVE

3 **TRAINING ISSUES / PROGRAMS**
- 429___ INADEQUATE INSTRUMENT TRAINING
- 430___ INSTRUMENT REFRESHER COURSE
- 431___ LOST WINGMAN TRAINING
- 432___ RADAR TRAIL DEPARTURE / RECOVERY
- 433___ SIMULATOR / PTT / CPT
- 434___ LOW LEVEL
- 435___ NIGHT
- 436___ NIGHT VISION GOGGLES
- 437___ WEAPONS EMPLOYMENT / RANGE
- 438___ FORMATION
- 439___ PROCEDURES / CHECKLIST DISCIPLINE
- 440___ LIFE SUPPORT / PERSONAL EQUIPMENT
- 441___ PHYSIOLOGICAL / CENTRIFUGE / SDO
- 442___ NO TRAINING FOR TASK ATTEMPTED
- 443___ FLIR (SYSTEMS)
- 444___ OTHER___________

4 **INDICATE WHERE TRAINING FACTORS OCCURRED**
- 445___ UPT / UNT / UHT
- 446___ LIFT
- 447___ RTU
- 448___ LOCAL CHECKOUT
- 449___ AMQT / MQT
- 450___ CONTINUATION TRAINING
- 451___ OTHER___________

5 **EVALUATION / PROMOTION / UPGRADE ISSUES**
- 452___ OFFICER EVALUATION SYSTEM
- 453___ UPGRADE PRESSURE
- 454___ SUPERVISOR OF FLYING
- 455___ FLIGHT LEAD
- 456___ MISSION COMMANDER
- 457___ INSTRUCTOR / EXAMINER
- 458___ RANGE OFFICER
- 459___ RUNWAY SUPERVISORY OFFICER
- 460___ OTHER___________

6 **WORKLOAD**
- 461___ ADDITIONAL DUTIES
- 462___ PROFESSIONAL MILITARY EDUCATION
- 463___ OTHER ACADEMIC ENROLLMENT
- 464___ SUPERVISOR TASKING
- 465___ OTHER___________

7 **UNIT PERCEPTIONS OF EQUIPMENT**
- 466___ LACK OF CONFIDENCE IN EQUIPMENT
- 467___ LACK OF CONFIDENCE IN AIRCRAFT
- 468___ LACK OF CONFIDENCE IN ESCAPE SYSTEMS
- 469___ UNIT PLANNING TO DEACTIVATE
- 470___ UNIT CHANGING MISSION / AIRCRAFT
- 471___ OTHER___________

FACTOR RELATIONSHIP

COMPLETE THE MATRIX BELOW **AFTER** RESPONDING TO ALL THE INDIVIDUAL AND ENVIRONMENTAL FACTORS. THIS AREA WILL ALLOW YOU TO ESTABLISH RELATIONSHIPS BETWEEN FACTORS.

RANK ORDER ALL FACTORS (BY NUMBER) THAT DEFINITELY CONTRIBUTED, ("MARKED 4"), FROM THE TOP DOWN IN THE LEFT COLUMN.

THEN, IN EACH ROW LIST ANY FACTORS RELATED TO THAT DEFINITE FACTOR, AGAIN IN **RANK ORDER** OF RELATIONSHIP HIGHEST TO LOWEST (LEFT TO RIGHT).

EXAMPLE:

DEFINITE FACTOR	*RANK ORDER OF RELATED FACTORS*
113	*140, 137, 165*
175	*262*

The evaluator is expressing that 113 is the GREATEST contributing factor, and is MOST related to 140, and is LESS related to 137, and is LEAST related to 165. 175 has less contribution than 113. 262 Is related to 175.

DEFINITE FACTOR HIGHEST	RANK ORDER OF RELATED FACTORS HIGHEST LOWEST
LOWEST	

IF NEEDED, CONTINUE WITH RELATIONSHIPS ON THE BACK.

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

4. LIFE SUPPORT EQUIPMENT

a. PERSONAL, SURVIVAL, & ESCAPE EQUIPMENT

ENTER INFORMATION ON EQUIPMENT LISTED AND INDICATE IF IT MALFUNCTIONED, CONTRIBUTED TO THE INJURIES OF THIS PERSON, OR WAS USEFUL. ENTER UNIT MDR NUMBER IF SUBMITTED.

ITEM DESCRIPTION (SPECIFY TYPE / NUMBER)			MDR #	CODE(S)
CLOTHING FLIGHT SUIT				
FLIGHT GLOVES				
BOOTS				
ANTI EXPOSURE SUIT				
HELMET				
	Before Emergency	During Egress	During PLF	
CHIN STRAP FASTENED				
NAPE STRAP SECURE				
VISOR LOWERED Single				
Dual				
Ans: Yes Snug= Y, No= N, Unk= U, Yes but loose= L				
OXYGEN MASK				
OXYGEN REGULATOR				
OXYGEN SUPPLY SOURCE/PRESSURE				
LIFE PRESERVER (LPU)				
AUTO INFLATOR				
EJECTION SEAT (IF ACES II CHECK MANUFACTURER) MDA [ ] WEBER [ ]				
SEAT RESTRAINT(S)				
HARNESS				
PARACHUTE				
AUTO ACTUATOR				
SURVIVAL KIT / VEST				
LIFE RAFT				
RADIO(S)				
BEACON(S)				
NIGHT VISION GOGGLES / DEVICES Complete additional form if involved				
ANTI G-SUIT / PRESSURE SUIT				
ANTI G-VEST (JERKIN)				
ENVIRONMENTAL CONTROL SYSTEM				
PRESCRIPTION GLASSES				
OTHER				

OTHER EXAMPLES: ELECTRO-OPTICAL DEVICES, CHEMICAL DEFENSE GEAR, ID TAGS, BODY ARMOR, PERSONAL LOWERING DEVICE, ETC.

CODE	CONDITION / PROBLEM
01	ACTUATED AUTOMATICALLY
02	ACTUATED BY ANOTHER PERSON
03	BOTH SIDES FAILED TO AUTO ACTUATE
04	LEFT OR RIGHT AUTOMATIC INFLATION
05	LEFT OR RIGHT SIDE FAILED TO AUTO ACTUATE
06	DIFFICULT ACTUATION
07	FAILED ACTUATOR
08	INADVERTENT ACTUATION
09	ADDED TO INJURIES
10	CONTRIBUTED TO INJURY
11	MINIMIZED INJURIES
12	PRODUCED INJURIES
13	USE HAMPERED BY INJURY
14	AIDED IN RESCUE/SURVIVAL
15	DETRACTED FROM RESCUE/SURVIVAL
16	BEYOND REACH
17	BURNED
18	CUT
19	DAMAGED
20	DELAYED IN USING
21	DESIGN DEFICIENCY
22	DESTROYED
23	DIFFICULT CONNECTION
24	DIFFICULT RELEASE
25	DIFFICULT RESTRAINT
26	DIFFICULTY LOCATING
27	DISCARDED
28	DONNING/REMOVAL PROBLEM
29	ENTANGLEMENT
30	ENTANGLEMENT WITH AIRCRAFT
31	ENTANGLEMENT WITH EJECTION SEAT
32	ENTANGLEMENT WITH PARACHUTE
33	FAILED
34	FAILED CONNECTION
35	FAILED RELEASE
36	FAILED RESTRAINT
37	INADVERTENT RELEASE
38	INSTALLATION ERROR
39	LANDED ON UNDEPLOYED SURVIVAL KIT
40	LEAKED
41	LOST
42	MATERIEL DEFICIENCY
43	NON-STANDARD CONFIGURATION
44	NOT AVAILABLE
45	OPERATED PARTIALLY
46	POOR FIT
47	PUNCTURED
48	TORN
49	NOT USED PROPERLY- HAD TRAINING
50	NOT USED PROPERLY- NO TRAINING
51	USE HAMPERED BY COLD
52	USE HAMPERED BY OTHER EQUIPMENT
53	USE HAMPERED BY WATER
54	USE UNFAMILIAR
55	FAULTY PREPARATION OF EQUIPMENT BY AIRCREW
56	FAULTY PREPARATION OF EQUIPMENT BY TECHNICIAN
57	MAINTENANCE ERROR
58	UNAUTHORIZED MODIFICATION TO EQUIPMENT
59	NOT REQUIRED BUT NEEDED
60	OTHER_______________

COMMENT ON IDENTIFIED EQUIPMENT PROBLEMS IN THE LIFE SUPPORT NARRATIVE.

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

4. b. ESCAPE DECISION AND DATA

(1) LOCATION IN AIRCRAFT
(CREW/PASSENGER SEATING)

(A) LOCATION

1___ COCKPIT CONTROL AREA
2___ NAVIGATOR/ENGINEER AREA
3___ CABIN/PASSENGER AREA
4___ OTHER___________
5___ UNKNOWN

(B) LONGITUDINAL LOCATION

1___ FORWARD
2___ CENTER
3___ AFT
4___ UNKNOWN

(C) LATERAL LOCATION

1___ CENTER
2___ LEFT SIDE
3___ RIGHT SIDE
4___ UNKNOWN

(D) DIRECTION FACING

1___ FORWARD
2___ AFT
3___ SIDEWARD
4___ UNKNOWN

(E) USE OF SEAT

1___ NOT IN SEAT
2___ IN SEAT
3___ BUNK
4___ UNKNOWN

(2) ESCAPE METHOD

(A) BY EJECTION

1____ ACCOMPLISHED
2____ INITIATED (DID NOT CLEAR COCKPIT)
3____ ATTEMPTED BUT INITIATION FAILED
4____ ATTEMPTED BUT SEQUENCING FAILED
5____ INADVERTENT EJECTION
6____ UNDERWATER EJECTION
7____ UNKNOWN IF ATTEMPT WAS MADE
8____ SUSPECTED EJECTION
9____ DEFINITELY NOT ATTEMPTED
10____ SEAT EJECTED ON IMPACT

(B) BY BAILOUT

1____ ACCOMPLISHED (FREE OF AIRCRAFT)
2____ ATTEMPTED (NOT ACCOMPLISHED)
3____ BAILED OUT AFTER EJECTION ATTEMPT FAILED
4____ UNKNOWN IF ATTEMPT WAS MADE
5____ SUSPECTED BAILOUT
6____ DEFINITELY NOT ATTEMPTED

(C) BY OTHER MEANS

1____ EMERGENCY GROUND EGRESS
2____ UNDERWATER EGRESS (NOT EJECTION)
3____ DID NOT ESCAPE
4____ EXIT UNASSISTED (OTHER THAN #1)
5____ CARRIED/ASSISTED OUT
6____ BLOWN/THROWN OUT
7____ JUMPED/FELL FROM AIRCRAFT IN FLIGHT
8____ UNKNOWN IF ESCAPE ACCOMPLISHED
9____ ESCAPE METHOD UNKNOWN

(3) ESCAPE INTENTION

1____ INTENTIONAL, OTHER-INDUCED
2____ INTENTIONAL, SELF-INDUCED
3____ UNINTENTIONAL, MECHANICAL
4____ UNINTENTIONAL, OTHER-INDUCED
5____ UNINTENTIONAL, SELF-INDUCED
5____ INTENT UNKNOWN

(4) REASONS FOR ESCAPE
(MARK ALL THAT APPLY)

1____ ARRESTMENT FAILURE
2____ ENGINE FAILURE
3____ FIRE OR EXPLOSION
4____ FUEL EXHAUSTION
5____ WATER IMPACT
6____ DEPARTED PREPARED SURFACE
7____ LOSS OF CONTROL
8____ MID-AIR COLLISION
9____ STRUCTURAL FAILURE
10____ IMPACT WITH GROUND OR STRUCTURE
11____ UNKNOWN IMPACT
12____ OTHER_______________

(5) EXIT USED

1____ NORMAL EXIT
2____ EMERGENCY EXIT
3____ EXIT THROUGH CANOPY
4____ NORMAL EJECTION
5____ UNKNOWN
6____ OTHER__________

(6) DELAY IN INITIATING ESCAPE DUE TO:
(MARK ALL THAT APPLY, SEQUENCE BY NUMBER)

1____ ADVERSE AIRCRAFT ATTITUDE
2____ ADVERSE BODY POSITION
3____ ATTEMPTING TO OVERCOME PROBLEM
4____ AVOIDING POPULATED AREAS
5____ AVOIDING UNSUITABLE TERRAIN
6____ EXCESSIVE AIRSPEED
7____ EXCESSIVE ALTITUDE
8____ INSUFFICIENT ALTITUDE
9____ UNKNOWN
10____ NONE
11____ OTHER ____________

(7) WAS DELAY IN INITIATING ESCAPE:

1____ APPROPRIATE
2____ EXCESSIVE
3____ UNKNOWN
4____ OTHER _____________

(8) TIME FROM ONSET OF EMERGENCY UNTIL ESCAPE ATTEMPT INITIATED.

HOURS ________
MINUTES ________
SECONDS ________

(9) COCKPIT CONDITION AFTER IMPACT

1____ NO DAMAGE
2____ MINOR DAMAGE (DEFINITELY HABITABLE)
3____ INTACT (PROBABLY HABITABLE)
4____ MAJOR DAMAGE (PROBABLY NOT HABITABLE)
5____ DESTROYED (DEFINITELY NOT HABITABLE)
6____ UNKNOWN
7____ AIRCRAFT ABANDONED IN-FLIGHT

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

4. c. EGRESS DIFFICULTIES

PLACE AN "X" IN THE APPLICABLE COLUMN
TO INDICATE IF THE PROBLEM DEVELOPED
BEFORE "**B**", DURING "**D**", OR AFTER "**A**" EGRESS
(APPLIES TO ALL AIRCRAFT)

	AIR			GROUND			WATER		
	B	D	A	B	D	A	B	D	A
1. ANTHROPOMETRIC PROBLEM									
2. BUFFETING									
3. CANOPY JETTISON FAILURE (Automatic Mode)									
4. CANOPY JETTISON PROBLEM									
5. COLD									
6. CONFUSION / PANIC / DISORIENTATION									
7. COULD NOT OPEN CANOPY / HATCH									
8. DARKNESS / NO VISUAL REFERENCE									
9. DIFFICULTY LOCATING CANOPY JETTISON MECHANISM									
10. DIFFICULTY REACHING HATCH/EXIT - AIRCRAFT ATTITUDE									
11. DIFFICULTY REACHING HATCH/EXIT - EQUIPMENT HANG-UP									
12. DIFFICULTY REACHING HATCH/EXIT - INJURIES									
13. DIFFICULTY REACHING HATCH/EXIT - OBSTRUCTIONS									
14. DIFFICULTY RELEASING CANOPY / HATCH									
15. DIFFICULTY RELEASING RESTRAINTS									
16. DROGUE SLUG STRUCK PERSON									
17. DROGUE SLUG SWINGING									
18. EJECTION HANDLE FAILED TO ACTIVATE SEAT									
19. EJECTION HANDLE PROBLEM (Locating, Reaching, etc.)									
20. FACE CURTAIN FAILED TO ACTIVATE									
21. FACE CURTAIN PROBLEM (Locating, Reaching, etc.)									
22. FAILURE OF LAP BELT									
23. FAILURE TO RELEASE CANOPY / HATCH									
24. FIRE / SMOKE / FUMES									
25. FLAILING - LOWER EXTREMITIES									
26. FLAILING - UPPER EXTREMITIES									
27. G FORCES									
28. HAMPERED BY CLOTHING									
29. HAMPERED BY EQUIPMENT (Including Body Armor)									
30. HAMPERED BY INJURIES									
31. INADVERTENT OPENING OF LAP BELT									
32. INDIVIDUAL STRUCK BY OTHER EQUIPMENT									
33. INRUSHING WATER									
34. LIFE SUPPORT EQUIPMENT FACTOR (Not hang-up)									
35. LOWER EXTREMITIES HIT COCKPIT STRUCTURES									
36. PARACHUTE CANOPY STREAMED / MALFUNCTIONED									
37. PARACHUTE CONTAINER DID NOT OPEN									
38. PARACHUTE LINE OVER / INVERSION / SEMI-INVERSION									
39. PARACHUTE RISER INTERFERENCE									
40. PERSON ENTANGLED IN RAFT LANYARD									
41. PERSON HELD ONTO SEAT									
42. PERSON STRUCK CANOPY / CANOPY BOW									
43. PINNED IN AIRCRAFT (Not equipment hang-up)									
44. SEAT FAILED TO FIRE									
45. SEAT LEFT IN SAFED CONDITION									
46. SEAT SEPARATION DIFFICULTY									
47. SEAT / PARACHUTE ENTANGLEMENT									
48. SEAT / PERSON COLLISION									
49. STRUCK EXTERIOR SURFACE OF AIRCRAFT									
50. TUMBLING / SPINNING (Person and / or seat)									
51. UNAUTHORIZED EQUIPMENT (Or modification of)									
52. UNCONSCIOUS / DAZED									
53. UPPER EXTREMITIES HIT COCKPIT STRUCTURES									
54. WINDBLAST									
55. NONE									
56. OTHER									

Other Examples: ENVIRONMENTAL SENSOR FAILED, DROGUE CANOPY OPERATED IN MODE ONE, ETC.

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4. d. EJECTION PARAMETERS

(1) BODY POSITION AT EJECTION

	(a)Head	(b)Pelvis	(c)Feet	(d)Arms
1 Optimal				
2 Forward				
3 Upward				
4 Lateral				
5 Unknown				

(2) WAS THE ZERO DELAY LANYARD A FACTOR?
YES _____ NO _____ If YES explain in narrative.

(3) ORDER OF ESCAPE #______ OF ______

(4) NUMBER OF PREVIOUS EJECTIONS ________

(5) MODE OF SEAT OPERATION ______ (ACES II ONLY)

(6) REMOVAL OF AIRCRAFT CANOPY
(Mark all that apply)

1____ Intentional
2____ Unintentional
3____ Unknown if intended
4____ By this individual
5____ By another individual
6____ By unknown means
7____ Definitely attempted
8____ Not attempted
9____ Unknown if attempted
10____ Successful
11____ Unsuccessful
12____ Using automatic sequence
13____ Using manual release
14____ Due to external force (explain) ___________
15____ Due to other method (explain) ___________
16____ Hinge failure

(7) POSITION OF EJECTION SEAT
1____ Full up
2____ Full down
3____ Full forward
4____ Full aft
5____ Intermediate position
6____ Unknown

(8) METHOD OF MAN / SEAT SEPARATION
1____ Did not separate
2____ Automatic (as designed)
3____ Manual override
4____ Other (explain) __________

(9) METHOD OF EJECTION INITIATION
1____ Arm rest
2____ Face curtain
3____ Lower ejection handle
4____ Command sequence
5____ Impact
6____ Fire
7____ Mechanical failure
8____ External force (explain) ___________
9____ Unknown

(10) AUTOMATIC LAP BELT RELEASE
1____ Did not open or release
2____ Released automatically as designed
3____ Opened manually
4____ Opened inadvertently
5____ Not connected
6____ Unknown how released
7____ Unknown if released

(11) AIRCRAFT PARAMETERS AT TIME OF ESCAPE
(Either inflight or after crash, ditching, etc.)
Enter numeric value or "X" to mark condition.

1. Altitude __________ (ft AGL)
2. Airspeed ___________ KIAS
3. Ground speed _________ KNOTS (if not airborne)
4. Sink rate _________ (ft / min)
5. Nose up ____________ °
6. Nose down ___________ °
7. Right bank ___________ °
8. Left bank ___________ °
9. _____ Inverted
10. _____ Nose down spin
11. _____ Flat spin
12. _____ Oscillating spin
13. _____ Tumbling
14. _____ Mushing
15. _____ Disintegrating
16. _____ Rolling
17. _____ Other ________ ___________________
18. _____ Unknown
19. Rate of roll _____ ° / sec
20. Rate of pitch _____ ° / sec
21. Rate of yaw _____ ° / sec
22. G Forces: (estimated) _____ X _____ Y _____ Z
23. In Ejection envelope? YES _____ NO _____ UNK____
24. Below Minimum Safe Parachute Altitude?
YES _____ NO _____ UNK____

4. e. PARACHUTE DESCENT DATA

COMPLETE THIS SECTION ONLY
IF A PARACHUTE DESCENT OCCURRED

(1) GENERAL DATA
Terrain clearance at time of parachute opening__________ (AGL)
Number of previous parachute descents_______________
Total weight under parachute _____________________
Surface winds (magnetic,knots) ____________________
Dragged by chute? _____ YES _____ NO _____ UNK
Distance dragged in YARDS ____________________
Time dragged in SECONDS ____________________
AFSEAWARS INSTALLED? _____ YES _____ NO _____ UNK

(2) METHOD OF DEPLOYING PARACHUTE
1____ Not deployed
2____ Automatic Main
3____ Manual Main
4____ Automatic Reserve
5____ Manual Reserve
6____ Unknown
7____ Other

(3) PARACHUTE OPENING SHOCK
1____ Negligible
2____ Moderate
3____ Severe
4____ Unknown

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

(4) SEQUENCE OF ACTIONS ACCOMPLISHED
(Number in order only if used)

	BEFORE LANDING	AFTER LANDING
1 Helmet visor raised		
2 Oxygen mask released-Manual		
3 Oxygen mask released-Automatic		
4 Life preserver Actuated-Manual		
5 Life preserver Actuated-Automatic		
6 Survival kit deployed-Manual		
7 Survival kit deployed-Automatic		
8 Four-line release pulled		
9 Life raft actuated-Manual		
10 Life raft actuated-Automatic		
11 Canopy releases actuated-Manual		
12 Canopy releases actuated-Automatic		
13 Helmet removed		
14 Gloves removed		
15 Closed canopy releases		
16 Boarded life raft		
17 Other ____________		

(5) OSCILLATIONS DURING DESCENT
(Use codes: N = Negligible, M = Moderate, S = Severe, U = Unknown)
1____ Before 4-line release
2____ After 4-line release
3____ Without 4-line release
4____ Increased by survival kit deployment

(6) PARACHUTE LANDING TECHNIQUES
(Indicate all that apply)
1____ Could not see
2____ Looking at horizon
3____ Looking down
4____ Proper PLF
5____ Fell backward
6____ Fell forward
7____ Muscles tensed
8____ Muscles too tense
9____ Knees together
10____ Proper arm position
11____ Other ____________

(7) PARACHUTE DAMAGE
(Indicate Number)
1____ Severed suspension lines
2____ Torn panels-minor
3____ Torn panels-major
4____ Missing panels
5____ Twisted Risers
6____ Other

(8) CAUSE OF PARACHUTE DAMAGE
1____ Dragging after PLF
2____ Fire/Thermal
3____ Fouled on aircraft
4____ Fouled on ejection seat
5____ Landing
6____ Opening Shock
7____ Trees
8____ Chemical
9____ Unknown
10____ Other ____________

(9) DIRECTION FACED AT PARACHUTE LANDING COMPARED TO DESCENT TRAVEL DIRECTION
1____ Directly facing
2____ Directly sideways
3____ Backward facing
4____ Quartering Towards
5____ Quartering Away
6____ Unknown

(10) TERRAIN OF PARACHUTE LANDING
(Indicate all that apply)
1____ Deep snow
2____ Dense woods
3____ Hard ground
4____ In trees
5____ Through trees
6____ Lake
7____ Marsh/Swamp/Mud
8____ River
9____ Rocks
10____ Runway overrun
11____ Sea/Ocean
12____ Soft ground
13____ Steep slopes
14____ Structure
15____ In/near power lines
16____ Unknown
17____ Other

5. SURVIVAL AND RESCUE DATA

a. GENERAL AND NOTIFICATION DATA

(1) TIME SEQUENCE OF EVENTS
INDICATE TOTAL TIME IN DAYS, HOURS, AND MINUTES

Total time from mishap to rescue completed (Individual aboard rescue vehicle or abandoned) ____________
Total time from rescue notification to rescue completed ____________

Time spent in the water without raft ____________

Time spent in life raft ____________

Total search and rescue time ____________

Did injuries or death result from delayed SAR effort?
YES ____ NO ____ (Explain in narrative)
SAR Report Attached YES ____ NO ____

(2) UNITS/VEHICLES THAT PARTICIPATED IN RESCUE

(a) PRIMARY RESCUE VEHICLE
Type rescue vehicle ____________ Unit ____________
Experienced problems? YES ____ NO ____
Nautical miles from departure base to rescue site ____________

(b) ASSIST VEHICLE(S)
(1) Number of other rescue vehicles used. ____________
(2) Type vehicle ____________ Unit ____________
Experienced problems? YES ____ NO ____
(3) Type vehicle ____________ Unit ____________
Experienced problems? YES ____ NO ____
(4) Type vehicle ____________ Unit ____________
Experienced problems? YES ____ NO ____

(3) WEATHER CONDITIONS AT TIME OF RESCUE
1____ Clear
2____ Fog
3____ Hail
4____ Overcast
5____ Rain
6____ Snow
7____ Thunderstorms
8____ Surface winds ________knots/ ________ °
10____ Visibility (miles) ________ Ceiling (ft) ________
11____ Temperature in degrees F: Water ______ °F Air ______ °F
12____ Wave Height ______ Feet Wave Frequency ______ per / min.

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

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Aug 89

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(4) ALERTING COMMUNICATIONS PROBLEMS

1___ Aircraft radio/IFF Inoperative
2___ Incompatible radio frequencies
3___ Language problems
4___ Poor radio procedures
5___ Locater Beacon Malfunction
6___ Poor radio reception/trans
7___ Telephone busy/INOP
8___ Poor message reception
9___ None
10___ Other___________

(5) RESCUE ALERTING MEANS
(Number in sequence)

1____ Airborne radio relay
2____ Crash phone
3____ Other phone
4____ Loss of radio contact
5____ Overdue report
6____ Loss of RADAR surveillance
7____ Radio MAYDAY call
8____ Smoke/Fire/Crash report
9____ Survival radio
10____ Other radio report
11____ Satellite report
12____ Survival locater beacon
13____ Survivor report
14____ Visual signal
15____ Witnessed
16____ Other

(6) DELAYS IN DEPARTURE OF RESCUE VEHICLES

1____ Communications INOP
2____ Completing previous mission
3____ Crew not available
4____ No crash site information
5____ Operator not available
6____ Vehicle not ready
7____ Adverse Weather
8____ Other___________
9____ None

(7) RESCUE VEHICLE PROBLEMS ENROUTE

1____ Unforecast Headwind
2____ High sea state
3____ Mechanical problems
4____ Nature of terrain
5____ Other Obstructions
6____ Low/Poor visibility
7____ Rescuers lost
8____ Adverse Weather
9____ Low ceiling
10____ None
11____ Other___________

b. SURVIVAL AND RESCUE DIFFICULTIES

(1) PROBLEMS LOCATING SURVIVOR

1____ Darkness
2____ Fog/Clouds
3____ Heavy seas
4____ Trees
5____ Precipitation
6____ Radio interference
7____ None
8____ *Could not visually distinguish survivor from terrain*
9____ Inadequate/Improper search
10____ Lack of correct information on survivor location
11____ Loss of radio/Radar contact
12____ Malfunction of Direction Finding equipment
13____ Survivor failed / unable to use signaling equipment
14____ Survivor improperly used signaling equipment
15____ Other___________________

(2) PROBLEMS THAT COMPLICATED RESCUE OPERATIONS

1____ Communication
2____ Darkness
3____ Entrapment in aircraft
4____ Equipment Failure
5____ Fire/Explosion
6____ Slowed- by helicopter downwash
7____ Weather
8____ None
9____ Hampered by personal equipment
10____ Inadequacy / Lack of medical equipment
11____ Inadequacy / Lack of rescue equipment
12____ Inadequacy / Lack of rescue personnel training
13____ Inadequacy / Lack of rescue vehicle
14____ Panic / Inappropriate actions of survivor
15____ Topography - Rough seas, mtns. etc.
16____ Survivor dragged / entangled with parachute
17____ Other ________________________

(3) LOCATOR MEANS (Number in sequence)

1____ Dye marker	16____ Aircraft radio after mishap
2____ Flare-hand held	17____ Fire/Smoke/Smoke flare
3____ Flashlight	18____ Flare - pen gun type
4____ Gunfire	19____ Flightsuit/Helmet
5____ Mirror	20____ Individual located without aid of signals
6____ Parachute	21____ Mishap observed
7____ Radar chaff	22____ Mishap site located without signals
8____ Signal wand	23____ Other aircraft directed rescue personnel
9____ Sonar buoy	24____ Personnel locater beacon
10____ Strobe light	25____ Radio or radar vector or DF steer
11____ Survival radio	26____ Raft/Vest/Poncho
12____ Tracers	27____ Signal(built by survivor,fire,markings,etc.)
13____ Very pistol	28____ Survivor located rescuers
14____ Voice	29____ Walkie-Talkie or other FM radio
15____ Whistle	30____ Other _________________

(4) INDIVIDUAL SURVIVAL PROBLEMS ENCOUNTERED

1____ Darkness	9____ Confused/Dazed/Disoriented
2____ Exposure	10____ Entanglement (Not parachute)
3____ Fatigue	11____ Inadequate cold weather gear
4____ Injured	12____ Inadequate flotation gear
5____ Thirst	13____ Lack of signalling equipment
6____ Topography	14____ Lack of other equipment
7____ Weather	15____ Unfamiliar with procedures/equip.
8____ None	16____ Other_________________

(5) RESCUE EQUIPMENT USED (Number in sequence)

1____ Basket
2____ Ladder
3____ Life Ring
4____ Raft
5____ Rope
6____ Sling
7____ Stretcher
8____ First aid equipment
9____ Helicopter platform
10____ Helicopter rescue boom
11____ Knife/Axe/Saw
12____ Make-shift carrier support
13____ Tree penetrator seat
14____ Horse collar
15____ Other___________

(6) FACTORS THAT AIDED RESCUE/RECOVERY

1____ Aircraft emergency escape system/design
2____ Availability of rescue equipment
3____ Coordination of rescue efforts
4____ Personal equipment releases/actuators
5____ Rescue personnel training
6____ Rescue procedures/ pre-accident plans
7____ Suitability of equipment
8____ Survivor's techniques
9____ Training of survivor
10____ Other_________________

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

(7) INDIVIDUAL'S PHYSICAL CONDITION
Times: After Mishap=AM, During Rescue=DR, After Rescue=AR

TIMES	AM	DR	AR
1 Fully functional			
2 Partially functional			
3 Immobile/unconscious			
4 Fatal			
5 Unknown / Lost			

6. TRAINING

a. EJECTION SEAT/PARACHUTE TRAINING

(Required for those who used an ejection seat/capsule or made a parachute descent and landing)

IF DATES UNKNOWN / NOT AVAILABLE, WAS TRAINING EVER COMPLETED? Y=YES, N=NO, U=UNKNOWN

	DATE OF LAST TNG (month/year)	VALUE OF TNG (use codes)
UNARMED EJECTION SEAT		
ARMED SEAT ON TOWER		
PARASAIL (LAND)		
PARASAIL (WATER)		
JUMP SCHOOL		
OTHER		

b. SURVIVAL TRAINING

WATER		
LAND		
JUNGLE		
ARCTIC		
COMBAT		
OTHER (		

c. PHYSIOLOGICAL TRAINING

CENTRIFUGE TNG		
PHYSIOLOGICAL TRAINING		
SPATIAL DISORIENTATION TNG		
EGRESS		
OTHER		

VALUE CODES
0 = No Importance; 1 = Definitely helped; 2 = Possibly helped; 3 = Lack of training possible factor; 4 = Lack of training definite factor; 5 = Unknown

7. REPORT DOCUMENTATION

a. FLIGHT SURGEON

Name and Grade ______________________

Duty Station ______________________

Did your training help you complete the investigation?
YES ____ NO ____ (Explain in narrative)

Date of report ______________________

Autovon Phone ______________
NUMBER of PREVIOUS INVESTIGATIONS______

Signature______________________

b. LIFE SUPPORT OFFICER

Name and Grade ______________________

Duty Station ______________________

Did your life support training help you complete the investigation? ____YES ____ NO (Explain in narrative)

Date of report ______________________

Autovon Phone ______________
NUMBER of PREVIOUS INVESTIGATIONS______

Signature______________________

c. OTHER LIFE SCIENCE CONSULTANTS

Name and Grade ______________________
Duty Station ______________________
Phone (AV or Comm.)______________________

Name and Grade ______________________
Duty Station ______________________
Phone (AV or Comm.)______________________

8. NARRATIVE INSTRUCTIONS

The life sciences narrative is used to describe the circumstances surrounding the mishap. Evaluate the person for his/her 72 hour history and their 14 day life style. Discuss job pressures, fatigue, physical state or state of mental, or emotional exhaustion. Explain duty days, non flying duties, workload, PME and advanced degree work.

Injuries incurred and their causes must be discussed.

Human factors involved must be discussed. Pay close attention to the factors previously identified as contributing to the mishap.

Life support equipment and any design deficiencies must be discussed.

Identify egress / ejection parameters and any associated conditions.

Survival and Rescue must be discussed especially if there is a FATALITY.

FINDINGS need to be derived from your deliberations and facts.

Make RECOMMENDATIONS based on the FINDINGS and recommend an OPR.

Conclusions must support the findings of the mishap board.

9 SUMMARY INSTRUCTIONS

When your narrative is completed write a summary of it that does not exceed 99 lines. This summary will be entered in the computer as the human factors summary.

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

CREW POSITION/PASSENGER	LAST NAME	SSAN	MISHAP DATE

THE HUMAN FACTOR PROBLEM IN THE CANADIAN FORCES AVIATION

by

Colonel J.F. David
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305 Rideau Street, Constitution Building 8/FL
NDHQ Ottawa, Ontario, Canada K1A 0K2

Fifty years ago, the Air Investigation Branch in the UK recognized the enigma of dealing with Human Factor Errors. Quote:

'Most aircraft accidents are due to 'Human Factors' but the failure is not necessarily solely that of the person involved in the accident. It may be due to errors or omissions in *training*, to faulty *design, maintenance* or to *poor organization*. While it is usually possible to decide with fair certainty when a mechanical failure occurs, the *human factors* are often obscure. There is a tendency only to look for a cause and for sufficient evidence to show whether or not the pilot was to blame <u>but</u> if all the factors which led to the accident are to be brought out a much more thorough survey is necessary."

Today, fifty years later, how far have we come in advancing the analysis of human factor errors in aircraft accidents/ incidents? What have we done on a world-wide basis to establish a meaningful human factor data base that can be used for prevention of aviation losses? The answer is very simply very little.

In the Canadian Forces, we have come a long way towards reducing aircraft losses (Fig. 1) through a very thorough causal analysis system and this has translated into further reductions in our minor incidents/

CANADIAN FORCES (RCAF)
AIRCRAFT ACCIDENT RATES
1954 TO 1991

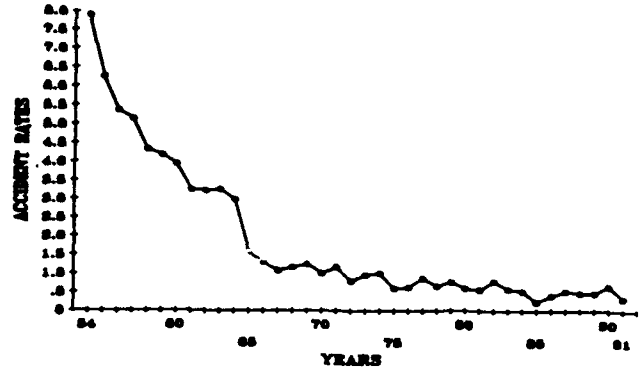

Fig. 1

damages as well. But throughout this evolution, the human factor error has consistently contributed to more than 83% of our losses. If we are to maintain this low plateau of losses today and/or further reduce our attrition, greater investment must be made in reducing the human factor errors. This cannot be done without a more detailed investigation into this area of concern and the development of a very detailed human factor error data bank. This data bank must necessarily cover all aspects of the life sciences (psychological, sociological, physiological) etc.

Quality of life issues and stress play an important role in our daily business. Is it possible to objectively assess these concerns? We all know stress affects us but how can we assess its impact on aircraft accidents? Is there a way of not compromising confidential medical information in the formation of an unclassified international or national human factor error data base? This paper is not intended to answer these questions but to reintroduce the dimension of the problem and the requirement for AGARD and the International community to work towards developing a human factor data base that is accessible and available for developing prevention programmes. As I see it, another 50 years is too long to wait.

I would like to share with you a 10-year analysis of human factor errors in the Canadian Air Force and hopefully show you where efforts should be concentrated to reduce human error.

The first slide is a 10-year analysis of our air accident cause factors (Fig. 2). Clearly, close to 83% of our air accidents were related to personnel failings. It could also be argued perhaps that 50% of the remaining items, such as materiel, environment, undetermined, and FOD, were personnel related. For example, did the materiel fail because of human engineering problems or design problems? Did the foreign object damage (FOD) to the engine come as a result of somebody leaving a bolt or nut in the intake, or on the ramp, or taxi area?

AIR ACCIDENT CAUSE FACTORS 1982 - 1991

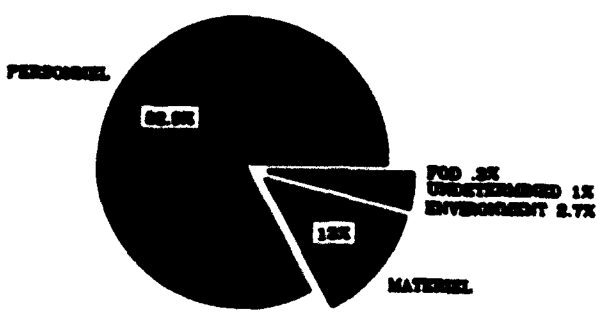

Fig. 2

The next slide covers a 10-year analysis of our ground accidents (Fig. 3); and interestingly, close to 84% of the causes were directly related to personnel errors. Similar arguments as for the previous slide can be made for personnel involvement in the "other" areas described on the slide.

GROUND ACCIDENT CAUSE FACTORS 1982 - 1991

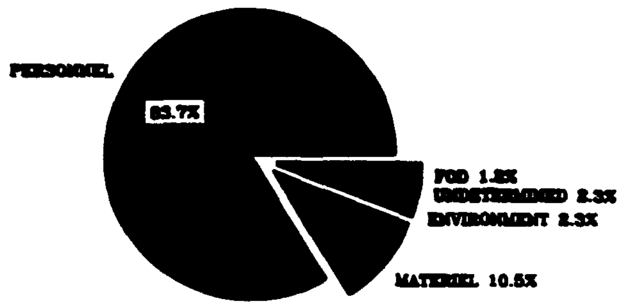

Fig. 3

Next, I would like to review all our ground and air occurrences that involved personnel error over the previous 10 years and show where the major failings occurred. Fig. 4 shows the four major contributors: Flight Crew, Support Personnel, Management and Supervisors. Interestingly, management failings remain fairly constant for both air and ground occurrences, the other three vary considerably. In the case of air occurrences (Fig. 5), the flight crew percentage is quite high, support personnel second and management and supervision still play a significant role. In the air, we would expect the flight crew errors to be high; obviously, because they are the ones who are flying the aircraft and have the greatest opportunity to make an error. In the case of ground occurrences (Fig. 6), we would expect support personnel to have the higher error rate as they are the ones most vulnerable and, the statistics support this. Although the overall supervisory error (Fig. 4) was approximately 10%, it represented only 6% of the personnel error in air occurrences and close to 19% in ground occurrences (i.e. 3 times greater).

PERSONNEL CAUSE FACTORS
AIR AND GROUND OCCURRENCES
1982 - 1991

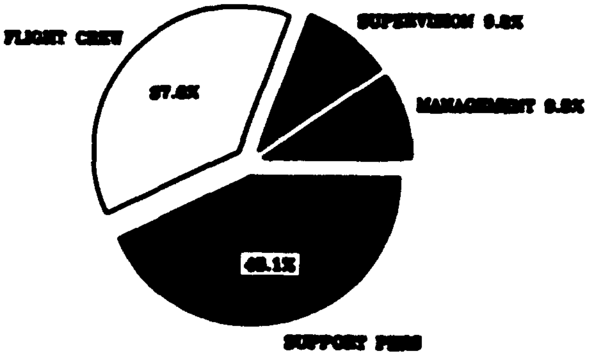

Fig. 4

PERSONNEL CAUSE FACTORS
AIR OCCURRENCES
1982 - 1991

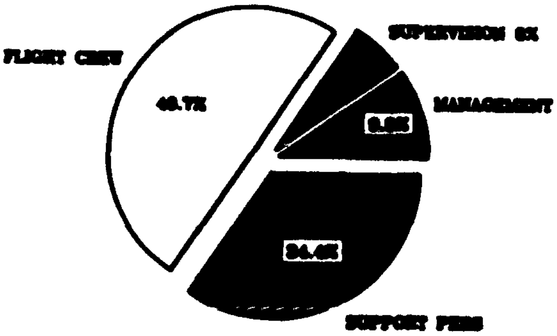

Fig. 5

PERSONNEL CAUSE FACTORS
GROUND OCCURRENCES
1982 - 1991

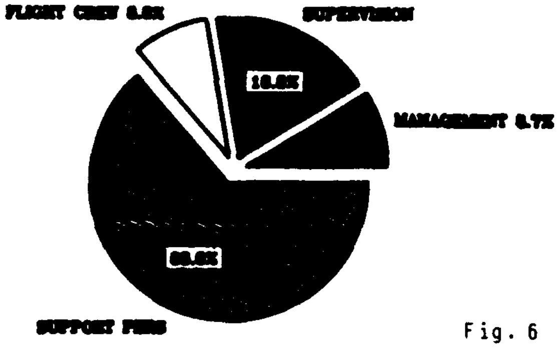

Fig. 6

Let's take a closer look at the 4 areas of concern where personnel play a role in contributing to accidents.

<u>Management</u> - (LCol and above)

Clearly management's ability to communicate effectively with those who support them would appear to be a major problem (44%) in air occurrences (Fig. 7). Judgement and resources are equally divided, however combined, they represent close to 49% of the management problems. The majority of these involve decisions on where money should be spent, whether or not resources should be made available in a timely manner, as well as decisions that involve delaying modifications to aircraft. Obviously, the timeliness of decisions and provision of resources play an important role.
In the case of ground occurrences, (Fig. 8) there is even a greater management info/ Communication problem with the technicians working on the aircraft (59% vice 44%). Once again, lack of resources contribute significantly, however, judgement error has dropped by 70%. The show-stopper message to management is that money and effort must be spent in improving basic communication

procedures, i.e. spend on the greatest problem area first especially when you cannot provide the resources.

MANAGEMENT CAUSE FACTORS
AIR OCCURRENCES
1982 - 1991

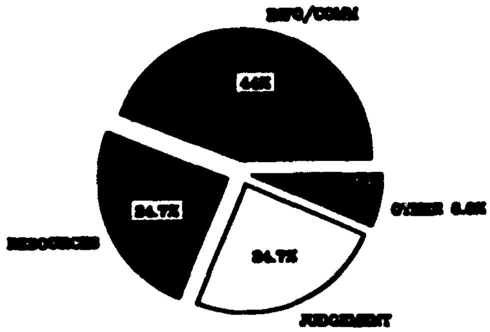

Fig. 7

MANAGEMENT CAUSE FACTORS
GROUND OCCURRENCES
1982 - 1991

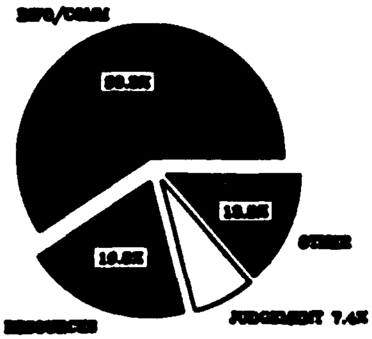

Fig. 8

Supervisor

When we take a look at the broad base supervisory level from LCol to MCpl, it is clear that inattention is a major failing. In the case of the ground occurrences, (Fig. 9) inattention and judgement are major areas of concern and like air operations, (Fig. 10) carelessness and complacency combine to represent close to 20% of the supervisory error.

SUPERVISION CAUSE FACTORS
GROUND OCCURRENCES
1982 - 1991

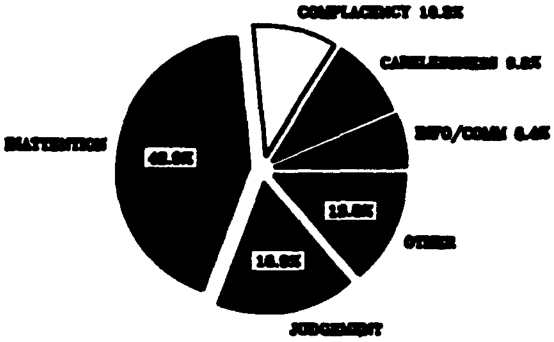

Fig. 9

SUPERVISION CAUSE FACTORS
AIR OCCURRENCES
1982 - 1991

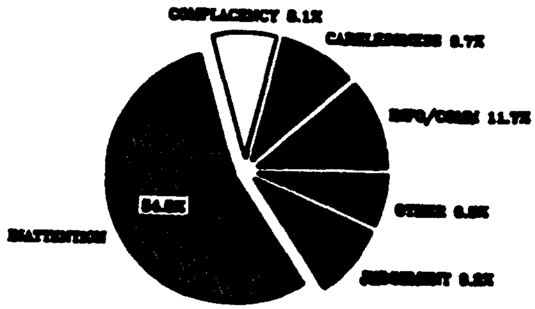

Fig. 10

Flight Crew

In analyzing flight crew error (the 38% problem), it becomes abundantly clear that inattention, technique and judgement are major areas of error in air occurrences (Fig. 11) and when we take a look at flight crew cause factors in ground occurrences, (Fig. 12) inattention is almost double, judgement is increased, and technique is reduced by more than 75%. Are people bored by taxiing the aircraft? Or is the task considered of such little importance by flight crews that the attention afforded is truly inappropriate for the tasking?

FLIGHT CREW CAUSE FACTORS
AIR OCCURRENCES
1982 - 1991

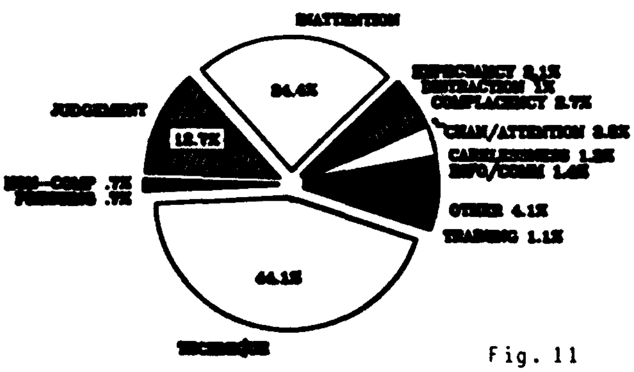

Fig. 11

FLIGHT CREW CAUSE FACTORS
GROUND OCCURRENCES
1982 - 1991

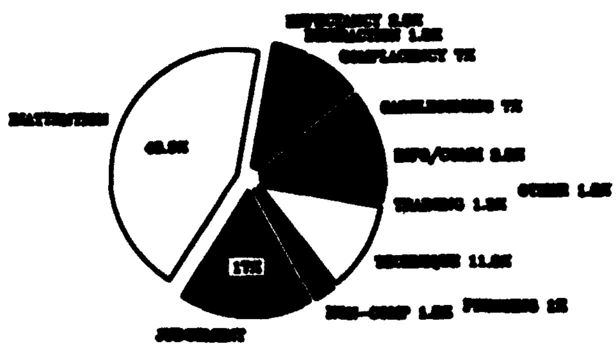

Fig. 12

Support Personnel

When we look at the support personnel cause factors in air occurrences (Fig. 13), inattention and technique are the major contributors. When we look at the ground occurrences (Fig. 14), for the same group of people, inattention, carelessness, technique and judgement are high.

With respect to the overall number of mishaps, both for on the ground and in the air, close to 62% of the human error is contributed by non-flight crew. This is important to consider in developing preventative measures; however one must keep in mind that 80% of the big dollar losses are associated with flight crew error.

SUPPORT PERS CAUSE FACTORS
AIR OCCURRENCES
1982 - 1991

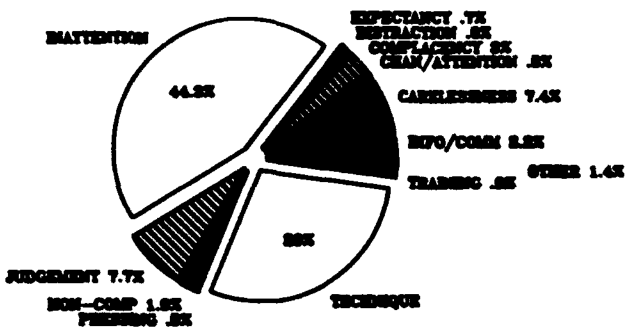

Fig. 13

SUPPORT PERS CAUSE FACTORS
GROUND OCCURRENCES
1982 - 1991

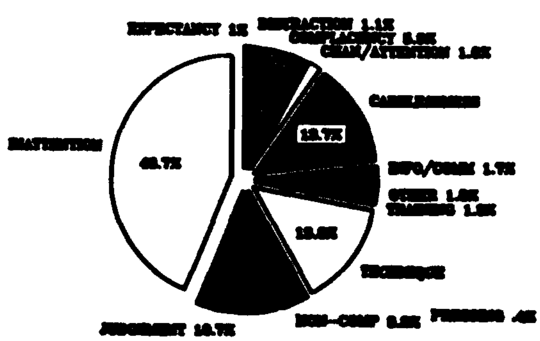

Fig. 14

Importance of Air Crew Training

In 1989, the Directorate of Flight Safety CF completed an analysis of aircraft losses in NATO (Fig. 15) and superimposed the annual mean flight hours invested per pilot (Fig. 16). This study was restricted to European based operations only, where mission taskings and environmental considerations were relatively neutral for all air forces. As figure 16 shows, there would appear to be a direct relationship between training and attrition. The better the investment in training, the lower the attrition rate (make a minimum investment now or pay larger sums later).

Notwithstanding this relationship, there appears to be overwhelming pressure to reduce training expenditures as part of the current peace dividend. Therefore, it makes even more sense today to try and transfer some of the inevitable "training savings" into human factor analysis and monitoring to hopefully reduce the human factor errors in aviation mishaps.

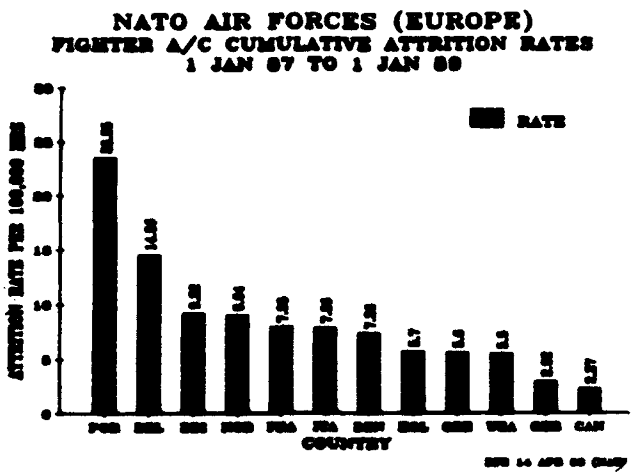

Fig. 15

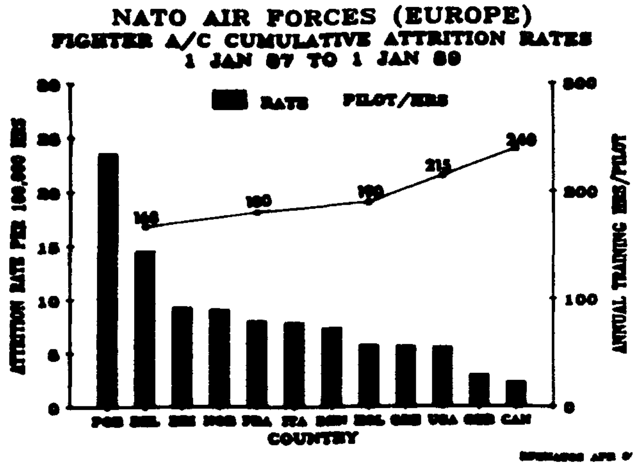

Fig. 16

Human Factor Checklists

The Canadian Air Force developed a human factor checklist for aircraft accident investigation over forty years ago. It has been the basis for the development of similar programmes in ICAO and a majority of NATO air forces. Despite this focussed approach to human factor errors, we have never created a human factor data base and have, therefore, compromised our ability to objectively assess the "83% problem".

The USAF has recently developed a computerized life sciences human factor accident investigation programme that will establish an Aircrew Error Data Base for air accidents only. The Transportation Safety Board of Canada have also developed a generic human factor data base for civil occurrences in Canada and is currently implementing the programme. Nevertheless, these programmes may not yet achieve the detail necessary to track the sociological and psychological areas of concern that we know play an important role in our daily efficiency and alertness which in turn impact directly on inattention and complacency, two of the major contributors to aviation losses.

Summary

Now that you have seen the statistics and the major areas of human error, what and where would you spend resources to prevent mishaps? Clearly, inattention, technique, communication, judgement, carelessness and complacency are the major failings. Where then do we have to concentrate our efforts to reduce these problems? I believe we need more emphasis on the sociology, (quality of life issues) and the psychology side of our business.

In my opinion, aviation psychology needs more investment. Furthermore, we cannot progress effectively in this area unless an extensive human factor data base is developed over the coming decades. A human factor data base will allow for meaningful and more objective assessment by the decision makers and leaders.

Major E.A. Brook
Directorate of Flight Safety, Canadian Forces
NDHQ Ottawa, Ontario, Canada K1A 0K2

Problems in Human Factor Data Collection

Human Factors are acknowledged as the prime cause of accidents in the Canadian Forces as well as in other military and civilian flying worldwide. Although human error accounts for over 80% of all accidents our Directorate of Flight Safety (DFS) does not have a system in place that can adequately manage Human Factors information. A recent study of the Canadian F-18 community concluded that the current aircraft accident database is not effective in facilitating remedial action on Human Factors issues.

The Canadian Forces led in developing detailed subordinate cause factors and assigning them in place of the infamous term "pilot error". A finding of judgement, technique or inattention, however, does not fully explain the circumstances leading up to an accident nor lead to effective preventive action. The final cause factor describes what happened not why. Other components, for which only soft evidence exists, such as nutrition, fatigue, or stress are left unrecorded. To study these problem areas further one must re-examine the original Boards of Inquiry or medical reports. Essentially this means doing the investigation twice. We clearly need to collect Human Factors information in a better and more meaningful way.

An abundance of personal information is already collected during accident investigations. Most of this is currently non-retrieveable. Investigators use checklists such as our "Human Factors

Guide for the Conduct of Aircraft Accident Investigation" but generally no standardized record of the data is kept. The report often does not include the answers to all questions, especially those not considered relevant at the time. This reveals a need to record systematically the pertinent human characteristics of all personnel causally involved in occurrences. The record should be as complete as possible even when some information does not seem applicable to that particular occurrence. For example to refine our knowledge of how acute fatigue may contribute to an accident it would be useful to know the quantity and quality of both rest and duty time for all personnel who were causally involved in similar occurrences. A similar case could be made for experience measured in age, and flying hours. Ideally the data should be available from all aircrew, and not just from those who were involved in occurrences, in order for any predictions or assessment of risk to be made.

A unified collection of Human Factors data could be used to analyze human error and perform meta-analyses of all occurrence reports. Such a system is essential to validate or refute associations between factors like vision, tobacco use, or fatigue and flight safety. Research results could be made available quickly to aid current investigations, and assist development for new aircraft systems.

Criteria for a Human Factors Database

An effective Human Factors database should possess the following properties. Information need be entered only once, at the place and time of occurrence. Subsequently, it should be simple for authorized personnel to validate and correct these facts . Personal data regarding individuals can be recorded either in a narrative format or in tables relating to checklist items with each record linked to a particular occurrence record in the main accident/ incident database.

The system should be user-friendly and easy to learn with minimal training. There should be operator-defined layouts for data entry and reporting. In Canada we require a bilingual format for the basic information. Access to the system and to sensitive portions such as the Human Factors area should be controlled by passwords. Reports should be automatically sterilized of privileged information. Of course a reliable high speed system with potential for expansion is essential. The ability to use a Natural Language Query system would be optimal for searching records. Whatever the format of a Human Factors database it should be capable of exchanging useful information with the systems of other military and civilian air safety organizations.

Privacy and confidentiality are always an issue when dealing with sensitive personal details. We prefer not to include classified information so as to make it more readily available. If the identity of individuals remains hidden except from select authorized users (such as Human Factors specialists) then privacy concerns should be minimal.

Design of a Preliminary Dataform

Following an initial meeting held last summer to address this topic in the Canadian Forces a draft format for recording data was designed. This was revised and presented at our annual Flight Safety conference in December 1991. A two page form was introduced. The initial section contained a cross-reference to the occurrence and individual characteristics such as medical category, duty times and experience levels. The second section included a list of 80 Human Factors which were to be marked as present or absent. When present their degree of contribution to the accident could be ranked from zero (non-contributory) to 3 (definitely causal). Our intention is use this tool to collect information from incidents as well as accidents. There was a mixed reception to this proposal for collecting Human Factors data. Some participants felt that that completing the Human Factors data form would require too much time and effort. We plan next to conduct a field trial to determine the actual time requirements.

We recognize that any checklist approach to categorizing Human Factors is somewhat arbitrary and that the factors selected will be of use only if there is validity and consistency in their assignment. A longer more comprehensive list was thought by some to be easier to understand and complete. The length has to be weighed against the time available, especially for an instrument that will be used on a daily basis for minor incidents. A glossary should be included so that users know precisely what the terms mean. Another limitation is that any form such as this tends to be completed subjectively by the informants based on their personal knowledge of the individuals concerned. Many operators were also wary of the way that personal information might be used. The issue of privacy remains a major problem in collecting Human Factors information. The perception that personal matters divulged by an individual might be later linked to themselves by name tends to inhibit candid disclosure.

Strategic Information Systems Plan

DFS is now developing a Strategic Information Systems Plan to update our accident/incident database. The conceptual data model allows for the inclusion of Human Factors information either as defined fields or simply as a narrative of up to 120 pages of text per entry. This plan is still evolving and will be adapted further following feedback from the flight safety community. An alternative approach might also be supported by this infrastructure — that of a Confidential Reporting System. With such a system persons who report incidents are not required to identify themselves or even the aircraft type involved. The essential element is the narrative — what happened in the reporter's own words. The formal reporting system omits some reportable incidents when no damage has occurred. We know for example that physiological problems like disorientation and G-LOC are grossly underreported. Human factors incidents reported through a separate confidential, anonymous system could still be recorded in our updated database as descriptive narratives. This way they would be available for analysis and the lessons learned could be promoted by the flight safety system in order to prevent further occurrences.

UNDERLYING CAUSES OF ACCIDENTS: CAUSAL NETWORKS

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SUMMARY

This paper describes recent thinking about Accident Causation Theory, accident investigation and accident prevention. The central notion is that human error as the primary cause of accident causation, prevales at all levels in any complex organization and that accidents are caused by a unique network of factors, generated not only by unsafe acts of front-line operators, but also by fallible management decisions and all kinds of (psychological) preconditions that exist in the operations environment. New approaches aiming at possibilities of proactive prevention are briefly touched.

INTRODUCTION

Since the beginning of aviation, increasing amounts of human energy and financial resources have been invested and are still being invested in the evidently ever lasting endeavour of technical improvement of aircraft and aircraft systems. Parallel with this development, a decreasing contribution of purely technical causes of aviation accidents and incidents can be observed. Although the absolute number of accidents decreased dramatically during the first half century of aviation, it seems to be increasingly difficult to further reduce accident rates by more than just very marginal percentages. What concerns the aviation psychology and human factors community more and more during the last decade, is the resulting emergence of human error as the primary factor in accident causation. It is important, however, to realize that in modern thinking about accident causation more emphasis is laid on the notion that human error is not the privilege of front-line operators, but that it is also an equally salient feature of all humans at all hierarchical levels of any complex organization. Although more will be explained about this further on in this paper, thinking about the prevalence of human error throughout any organisation can best be illustrated by quoting from Reason (1990):"...the more removed individuals are from...front-line activities, ...the greater is their potential danger to the system."

ACCIDENT INVESTIGATION HISTORY

A quick overview of how aircraft accident investigation developed until today, reveals the following. In the early days a heavy emphasis was laid on the technical investigation and only when the investigating team could not find any plausible technical cause, it was concluded that "pilot error" most probably had caused the accident. At best it was described in the accident report WHAT the mishap pilot had done wrong or WHAT critical item he omitted thus causing the accident. It was not before the end of the seventies that people in the aviation organizations slowly began to realize that prevention of accidents could only be possible after having answered the all important question WHY the pilot made that particular error or WHY he omitted a critical action. To answer this question, however, aviation psychologists or human factor specialists were needed. So human factor specialists began to play an increasing role in accident investigation teams, although this development was and, to some extent, still is hesitant in some types of organization.

RESULTS OF ACCIDENT INVESTIGATION

Till today, it is Standard Operating Procedure (SOP) to wait till an accident happens, then investigate it and , if applicable, take remedial action in order to prevent the same accident from happening again. Necessarily this is a purely reactive form of accident prevention. It is also normal practice that, as a result of this kind of post hoc investigations, new regulations are issued, another warning is added, a procedure will be changed, the supervision level is raised. Also new DO's and DON'T's are formulated or a human-machine interface, like for instance a cockpit lay-out, will be changed. Although this is not bad practice, thinking about accident investigation and prevention could be challenged by, again, quoting from Reason (1990):"...while it is sensible to learn as many remedial lessons as possible from past accidents, it must also be appreciated that such events are usually caused by the unique conjunction of several necessary but singly insufficient factors. Since the same mixture of causes is unlikely to recur, efforts to prevent repetition of specific active errors will have only limited impact on the safety of the system as a whole."

ACTIVE FAILURES

In quoting from Reason the concept of active errors, also called active failures, was introduced. Figure 1 gives an overview of the most recent Accident Causation Theory. A very important distinction should be made between active and latent failures. Active failures or unsafe acts are actions or omissions on the part of the front-line operator (pilot, navigator, airtraffic controller etc.) that directly have their inadvertent effects on the sequence of events during actual operations and that in most cases are the direct causes of accidents. Examples of categories of unsafe acts are:

- Attentional failures like intrusions, omissions, reversals, misorderings and mistimings.
- Memory failures like omitting planned items, place-losing and forgetting intentions.
- Failures like misdiagnosis, misperception of hazards, corner cutting etc.

LATENT FAILURES

On the other hand (figure 1), latent failures constitute potential conditions for accident opportunities, but they may stay "underground" for, sometimes, long periods of time, until one day they become evident in combination with other causal factors. An unsafe act is always the last element in a chain that starts with latent failures. Furthermore all complex systems have defences, normally built up during the life of the organization as it learnt from previous accidents and incidents. But time and again there always turns out to be a hole in these defences, called a limited window of accident opportunity.

FALLIBLE DECISIONS

Designers and decision makers at the high-level management create fallible decisions. It is not necessarily a question of incompetence or carelessness, but in most cases it is the result of the forced allocation of limited resources to making a product (for instance air transportation in civil airlines or air superiority in the air force organizations) as well as to safety. If you spend more on production, you have less to invest in safety and vice versa.

LINE MANAGEMENT DEFICIENCIES

Furthermore fallible decisions on the highest management level can cause deficiencies in the line management. It depends on the quality of the line management whether fallible decisions of the higher level will be amplified, mitigated or almost nullified. However, deficiencies can also find their origin in the line management level. Till now eleven different failure types are distinguished in the literature (Wagenaar, Hudson & Reason, 1990):

- Hardware defects
- Design failures
- Missing defences
- Negligent housekeeping
- Error enforcing conditions
- Poor procedures
- Training deficiencies
- Organizational failures
- Incompatible goals
- Lack of communication
- Poor maintenance

PSYCHOLOGICAL PRECURSORS OF UNSAFE ACTS

Psychological precursors or preconditions (figure 1) are the potential sources of a wide variety of unsafe acts or active failures. Whether certain acts will lead to an accident, depends on the complex interactions between the task to be performed at any given moment, the particular dynamic environment in which the task has to be performed and the dangers and hazards that are present during that particular period of time. Depending on the typical conditions of any given moment during performance of the task, each psychological precursor can lead to a large number of active failures. Some examples of psychological precursors are:

- Inattention
- Undue haste
- Stress
- High workload situation
- Insufficient cues
- Competing demands
- Ignorance
- Complacency
- Poor motivation
  Etc.

Thus, starting with fallible decisions the network of causes branches more and more while we proceed through the line management deficiencies and the psychological precursors to the unsafe acts by the front-line operators. Again, Reason (1990) is rather straightforward in judging unsafe acts by front-line operators:"Rather then being the main instigators of an accident, operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking."

Figure 2 depicts how the dynamics of accident causation come to life. It can be seen that a complex combination of latent and active failures is necessary for the trajectory of accident opportunity to find a hole in each and every plane and in all the defence layers. It is easy to understand why the chance that a particular active error will lead to disaster, is very small.

IMPOSSIBLE ACCIDENTS

One more thing should be mentioned about accident investigation and prevention. Research has shown that accidents appear to be the result of highly complex coincidences which could rarely be foreseen by the people involved in the accident. The unpredictability is caused by the large number of causes and by the spread of the information over the participants. Accidents do not occur because people gamble and lose (although this also happens sometimes), they occur because people do not believe that the accident that is about to occur is at all possible. This "impossible accident" concept stems from Wagenaar and Groeneweg (1987) and, although the research that brought them to this conclusion was based on the analysis of accidents at sea, it can easily be generaralized to the aviation environment.
This notion together with the stochastic character of the many-to-many mappings of general failure types, psychological precursors and unsafe acts reveals, as Reason has put it, the futility of focusing the remedial efforts upon preventing the recurrence of specific unsafe acts. Although certain of these acts may fall into an easily recognizable subclass and so be amenable to targeted safety programmes and training, most of these acts are unforeseeable, sometimes even quite bizarre.

HINDSIGHT BIAS

An additional problem is that the team that has investigated an accident knows how the sequence of events was going to turn out, whereas the participants in the accident did not. This is a very significant psychological difference and research has shown that the outcome knowledge has a tremendous influence on the way all the events that led to that outcome, are evaluated. This so called hindsight bias unwittingly leads to misjudgment of what the players in the accident drama should have anticipated in foresight and to overestimation on the part of the investigators as to what they would have known had they not possessed knowledge of the outcome.

NEW APPROACHES

What should be done now that the old, trusted way of accident investigation and prevention seems to be a strong-but-(partially)wrong believe in solving the problem? Figure 3 encompasses all the elements of the Accident Causation Theory. Beside the already familiar concepts of latent failures (fallible decisions and line management deficiencies, combining into general failure types) and psychological precursors as well as active failures (unsafe acts) and system defences, several feedback loops can be seen here. Loop 1 represents the flow of (retrospective) safety information as is conveyed by accident reports etc. This is , as we have seen, the normal way we deal with safety; the events we would like to eliminate have already occurred. The loops 2, 3 and 4 seem more promising in preventing accidents because they give information before the accident will actually happen.
At the University of Leiden (The Netherlands) the working group "Safety" of the Psychological Faculty has designed a method of analysing general failure types. The result of this analysis is a so called Failure State

Profile (FSP), which gives indications as to which general failure types are prevalent in a given organiza tion. A basic feature of this approach is the search for (observable) indicators of the different general failure types. The first phase in the procedure is analysis of a number of accidents and incidents that happened in that particular organization. Of each and every event a causal network is described, which is a very laborious task. When the "tree" is finished, the different events can be attributed to the eleven general failure types. The ultimate goal is to design questionnaires which can be completed by people at all levels in the organization. Thus on a regular basis FSP's can be composed which give insight into the health conditions of the organization. This approach, called TRIPOD, is rather new. It has been implemented in desert drilling operations and on North Sea Platforms, but it has not yet been applied in the field of aviation. It looks, however, very promising and a research project to evaluate the method for application in aviation (in the Royal Netherlands Air Force) just started. Also in the RNLAF a system, called MIRROR, will be introduced on an experimental basis that monitors the risk state of an operational fighter squadron. The target is to give the squadron commander feedback information about the safety status of his squadron and thus an opportunity for proactive preventive measures. Hopefully positive results can be published in the near future.

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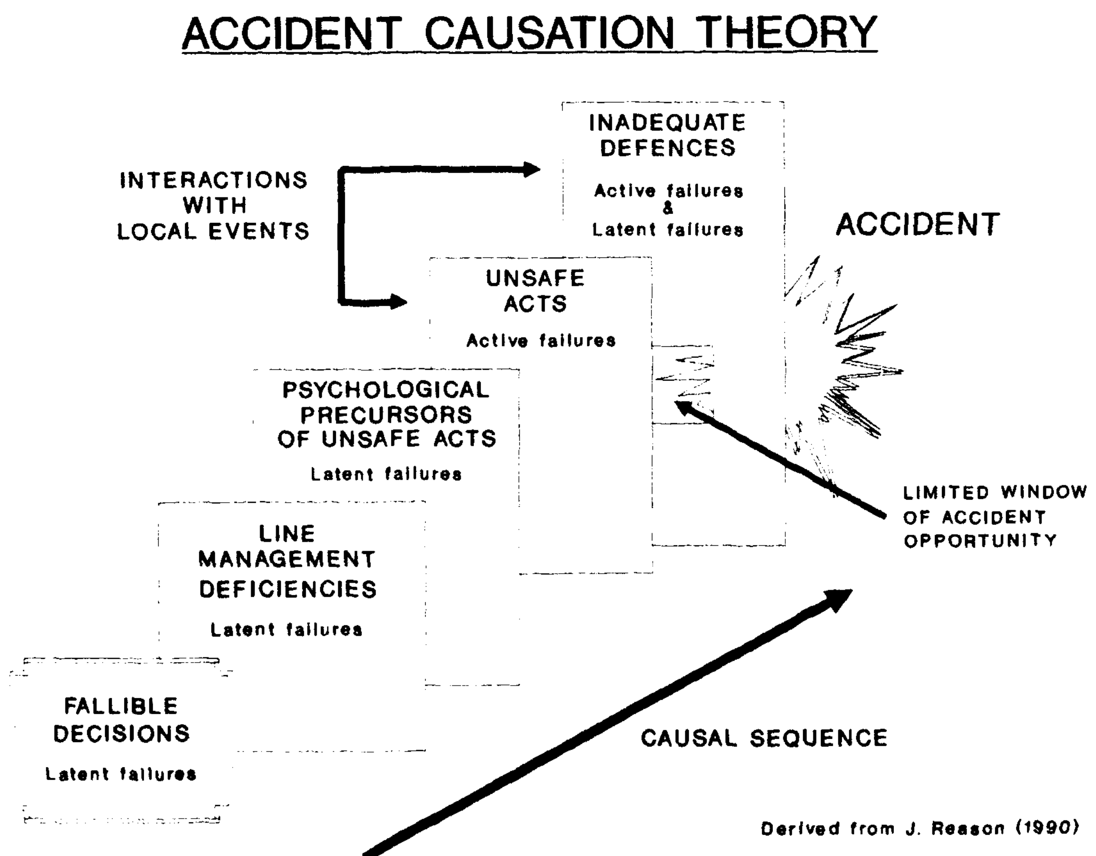
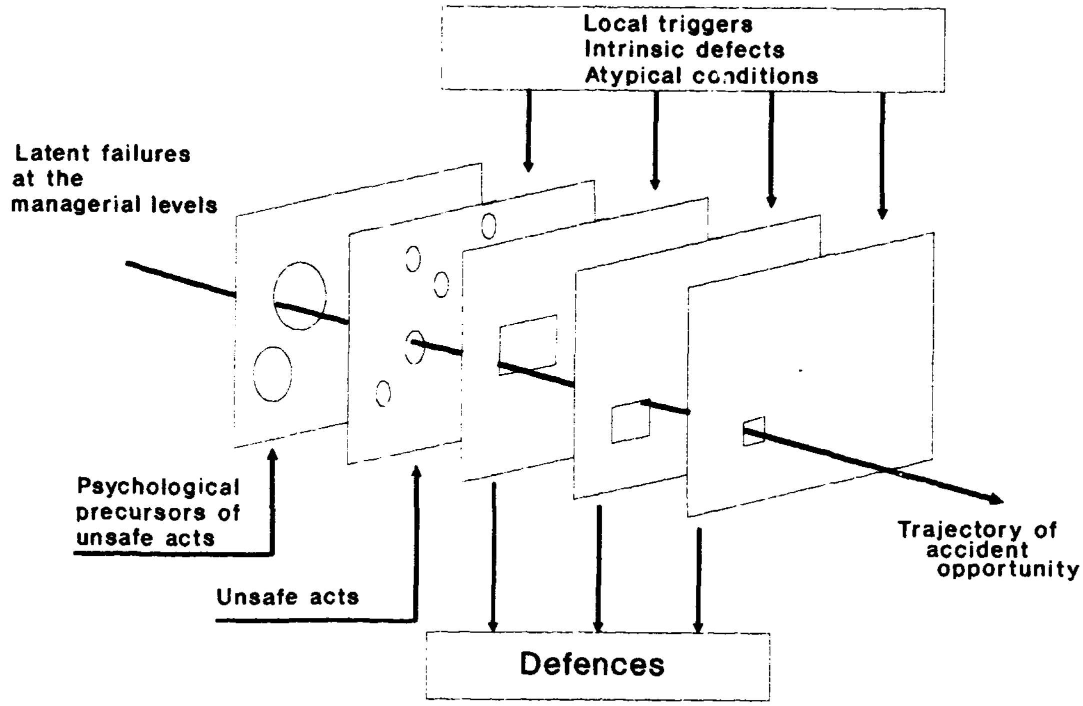


Figure 1

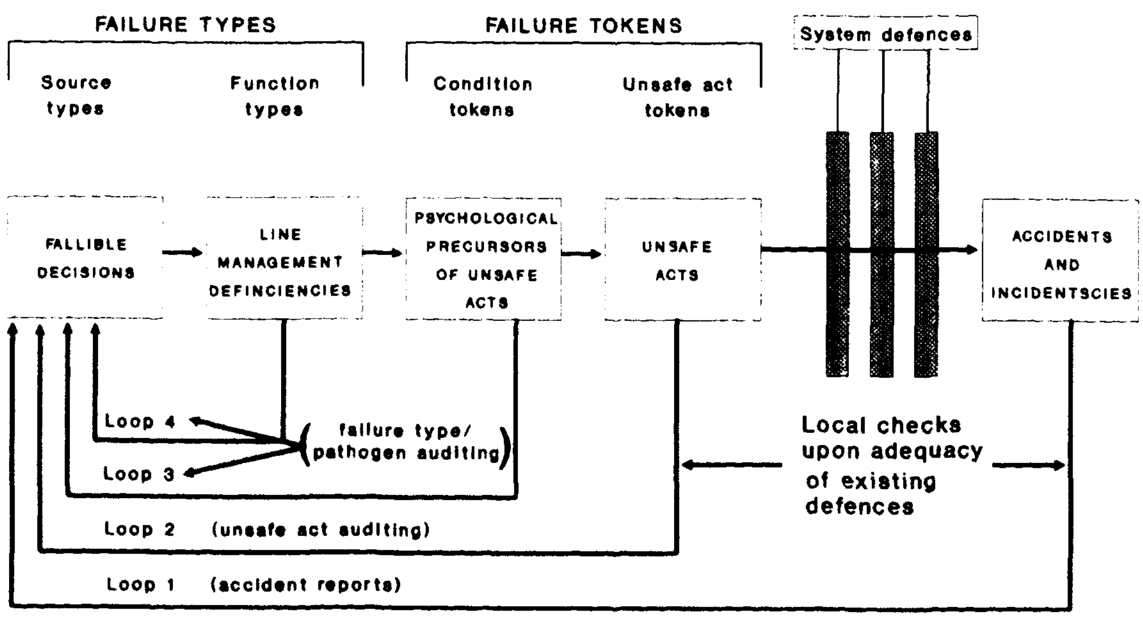
DYNAMICS OF ACCIDENT CAUSATION



Derived from J. Reason (1990)

Figure 2

ACCIDENT CAUSATION THEORY



Derived from J. Reason (1990)

Figure 3

AIDE A L'ENQUETE PAR FIGURATION ANIMEE

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1 - SOMMAIRE

L'enquête sur les causes d'un accident est une démarche de plus en plus difficile car les facteurs humains deviennent largement prédominants avec plus de 75 % des cas et chacun sait qu'ils sont délicats à interpréter. De plus le matériel comportant de plus en plus d'électronique et de logiciels, les traces physiques sont souvent inexistantes, hors les paramètres enregistrés sur "crash recorder" et CVR.

Lors de l'analyse des listings ou tracés, on interprète facilement les paramètres indépendants ou peu corrélés : régime et température moteur par exemple. Par contre, les paramètres évoluant rapidement et corrélés à plusieurs sont d'une approche laborieuse : réponse d'un avion à des sollicitations longitudinales et transversales combinées par exemple.

Un logiciel permettant la présentation sur une console graphique des paramètres enregistrés comme les voit le pilote et animés en temps réel a été réalisée sur la base d'essais de DASSAULT AVIATION à Istres. Le résultat satisfait tous les espoirs : il est possible de visionner le vol à la cadence normale, au ralenti, en accéléré, ou d'arrêter sur une image. La planche de bord est analogue à celle de l'avion, la manette et le manche bougent comme les vrais. L'horizon du paysage donne une information paravisuelle des mouvements de l'avion.

Les enquêteurs "sentent" réellement la façon dont le pilote a réagi aux mouvements de l'avion ou aux événements qui survenaient : signes d'inattention, de nervosité ou même changement de pilote aux commandes sur un biplace.

Dans une autre présentation, une maquette vue de l'extérieur reproduit les mouvements de l'avion pour l'analyse des évolutions complexes : vrilles, décrochages, etc ...

Enfin des tracés, avec ou sans zoom, donnent l'évolution des paramètres désirés en analogique, comme sur papier, mais avec plus de souplesse d'emploi.

Un film vidéo présentant quelques cas de vol typiques est destiné à faire ressortir les avantages de ce genre d'animation.

Description des opérations d'acquisition des données d'un avion militaire.

Organigramme du logiciel de présentation sur console graphique.

2 - IMPORTANCE DES FACTEURS HUMAINS.

Les statistiques montrent une diminution importante du nombre d'accidents aériens, principalement dans le transport civil. C'est la partie due aux incidents mécaniques qui est réduite de façon assez spectaculaire. Par contre les problèmes liés aux facteurs humains ne montrent pas une tendance aussi marquée, d'où une montée relative dans les pourcentages.

Suivant les auteurs les facteurs humains constituent 70 à 75 % des causes d'accident.

On relève un pourcentage plus faibles sur avions militaires, avions de combat monoplaces en particulier, car les causes dues à l'environnement, aux déficiences mécaniques ... sont plus fréquentes.

Dans cette catégorie, le pourcentage d'accidents dus aux facteurs humains se situe dans la tranche 45 - 60 %.

3 - DIFFICULTE D'INTERPRETATION.

La déficience mécanique peut être cernée lors d'une enquête minutieuse ; des exemples récents ont montré la précision étonnante des conclusions tirées lors d'accidents comme le DC10 d'Ermenonville, le B 747 de Lockerbie, le DC 10 d'UTA au Tchad.

Par contre l'erreur humaine est plus difficile à invoquer dans de nombreux cas, car si l'équipage ne survit pas à l'accident, les explications sont généralement inaccessibles. On constate une suite d'événements mais le fil conducteur n'est pas évident. Il faut à l'enquêteur une très bonne connaissance des conditions d'emploi de l'appareil pour qu'il puisse s'imaginer à la place de l'équipage et tâcher de faire coïncider ses propres réactions avec celles que révèlent les enregistrements. Toutes les interventions extérieures sont à envisager pour expliquer (le ou) les disfonctionnements humains.

Il est donc important de sentir avec la meilleure précision la façon dont les actions ont été menées, ce qui est quasiment impossible à la lecture des listings et reste difficile à l'examen de graphes.

4 - LA REPRESENTATION IMAGEE DES PARAMETRES.

a - La planche de bord reconstituée.

Pour faciliter la tâche de l'enquêteur et lui présenter l'exploitation des paramètres du crash recorder de la façon la plus parlante pour lui, nous avons réalisé sur la Base d'Essais DASSAULT AVIATION à Istres un logiciel permettant de présenter sur une console graphique une reconstitution du cockpit de l'avion (fig. 1).

Tous les paramètres existants sont représentés sur leurs indicateurs habituels : assiettes et caps sur une boule, régime et T_4 sur des instruments moteur, le temps sur la montre classique. Des indicateurs supplémentaires synthétisent d'autres informations, en particulier les mouvements du manche sont figurés par une pastille se déplaçant dans un rectangle comme la tête du manche entre ses butées. La position neutre est repérée par deux alidades. De même le repère de la manette des gaz se déplace dans un curseur gradué de Stop à PC maxi en passant par ralenti et PG sec.

Les témoins de fonctionnement et alarmes sont disposés comme sur l'avion réel et s'allument de la même façon.

Pour le réalisme, une vue extérieure avec horizon "naturel" reproduit ce que verrait le pilote en conditions VFR. Le paysage se résume à une texture verte pour le sol et bleue pour le ciel.

Sur cette surface claire peuvent s'inscrire, à la demande, les valeurs des différents paramètres exprimées en unités physiques et identifiées en toutes lettres, ainsi que la transcription sans ambiguïté des différents états des systèmes : train rentré ou sorti, pilote automatique en service, enclenché ou connecté, etc ...

b - La maquette dans l'espace.

La vue extérieure d'une maquette de l'avion permet de représenter ses attitudes et son cap pour un observateur situé au sud de la maquette, au même niveau et à distance constante (fig. 2).

Les assiettes, le cap, la vitesse et l'incidence sont inscrits en numérique en haut de l'écran.

Les paramètres en chiffres peuvent être appelés comme dans la présentation cockpit, en blanc sur fond noir.

c - Les tracés :

Il ne faut pas nier leur utilité ! Le synchronisme de deux événements peut s'observer bien sûr au passage, sur deux cadrans différents, s'ils sont proches. Mais il est plus agréable de le vérifier sur deux tracés en fonction du temps que l'on appelle sur cette troisième présentation avec possibilité de zoom sur l'échelle de temps (Fig. 3).

d - L'animation en temps réel.

La possibilité d'animer cette planche de bord en <u>temps réel</u> est l'avantage déterminant de cette représentation. La nervosité éventuelle du pilote apparaît clairement au travers des mouvements de manche et manette. Les mouvements de l'avion s'analysent beaucoup plus aisément qu'à l'examen des tracés représentant les assiettes ou les positions de gouverne.

La corrélation mouvements de manche, évolutions de l'avion est parfaitement accessible au pilote enquêteur qui connaît l'avion. Il peut apprécier à tout moment la situation de l'avion dans l'espace, l'énergie disponible, la nécessité ou non de modifier la poussée, ou bien le facteur de charge : sur un biplace, il peut ainsi déterminer qui pilote, de l'élève ou de l'instructeur.

Tout cela lui est accessible car il se sent dans l'avion, il est pratiquement en vol.

e - Le ralenti ou l'accéléré, l'arrêt sur image.

Une fois acquise en temps réel la séquence complète de vol et les actions pilote associées, il peut être intéressant de détailler ce qui s'est passé à un moment précis, un événement fugitif noyé dans une phase très agitée.

Il suffit de choisir la touche "ralenti" ou d'arrêt sur une image, comme sur un magnétoscope moderne.

Le défilement accéléré, si pratique pour retrouver une séquence particulière est également disponible sans aucune "griffure" des images.

De plus, il est possible de débuter une "lecture" ou de la reprendre à un instant précis que l'on affiche par le clavier. Les données étant en mémoire vive, l'action démarre instantanément.

f - Le film vidéo : instruction et prévention.

A condition d'employer pour la prise de vue un matériel vidéo professionnel qui peut se synchroniser sur la fréquence de balayage du tube cathodique, il est facile d'enregistrer les images de la console quelle que soit la vitesse de reproduction choisie et de faire ainsi très facilement le montage d'un film vidéo, aux fins de démonstration ou d'instruction.

Cette facilité est employée maintenant chaque fois qu'un accident ou un incident se produit.

La présentation du film participe de façon très efficace à la prévention, qui est, comme chacun le sait, le but recherché par tous les organismes de Sécurité des Vols.

Le film qui va être présenté maintenant est une bonne démonstration de toutes ces possibilités.

Le vol dont il est tiré est une séance d'entraînement de voltige à basse altitude sur MIRAGE 2000 en vue de la Présentation du Bourget.

Deux planches de tracés, des paramètres de vol classiques, coloriés pour en faciliter la lecture, sont présentés avant le film. Le spectateur appréciera mieux ainsi l'aide qu'apporte l'emploi de la console graphique (Fig. 4 et 5).

5 - L'ACQUISITION DES DONNEES.

Nous nous limiterons à l'examen du système actuellement en service sur les avions militaires.

A bord de l'avion, un boîtier réalise l'acquisition des divers paramètres choisis et envoie un message série à l'enregistreur magnétique qui se trouve dans une enceinte spéciale destinée à le protéger des chocs d'un crash et même du feu s'il ne dure pas trop longtemps. Actuellement la bande magnétique est progressivement remplacée par des mémoires statiques dont la sauvegarde est assurée par des piles. Elles sont protégées de la même façon.

L'exploitation de ces enregistrements débute par une décommutation des paramètres qui sont ensuite comparés à leur étalonnage, traduits en unités physiques puis mis en forme pour être stockés sous forme de fichiers sur le disque dur de la console graphique (Fig. n° 6).

6 - LE LOGICIEL ; L'ORGANIGRAMME.

Lorsqu'un utilisateur désire analyser un vol, le fichier correspondant est chargé en mémoire vive ; les images de fond, planche de bord, cadrans sont également mises en mémoire de visualisation.

Suivant les choix effectués, type d'avion, présentation désirée, cadence, etc .. le logiciel anime l'image désirée suivant l'organigramme présenté à la figure 7.

7 - L'EVOLUTION.

L'animation du cockpit par les paramètres de l'enregistreur de crash a pour premier objectif l'amélioration des moyens d'analyse des accidents ou incidents.

Cependant, au delà de cette restitution du vol, il est souhaitable d'étendre la collecte des données à celles qui intéressent la mission opérationnelle, permettant ainsi de rejouer ces missions aux fins d'instruction ou de contrôle. Ceci suppose l'utilisation d'un autre support d'enregistrement non protégé mais plus performant et le développement de nouveaux logiciels de présentation des résultats, avec des spécialisations évidentes : combat aérien à plusieurs avions, tir de missiles à moyenne ou grande portée ou contrôle d'une mission de pénétration en suivi de terrain.

8 - CONCLUSION.

La réalisation et la mise au point de ce dispositif ont été menées à bien grâce à une petite équipe de spécialistes unissant leurs connaissances et portés par un réel enthousiasme dans la recherche de la présentation. Partant d'un projet un peu vague ils l'ont transformé en un outil de grande efficacité, très bien adapté à l'utilisation par des pilotes. Merci aux informaticiens qui ont un tel "sens de l'air".

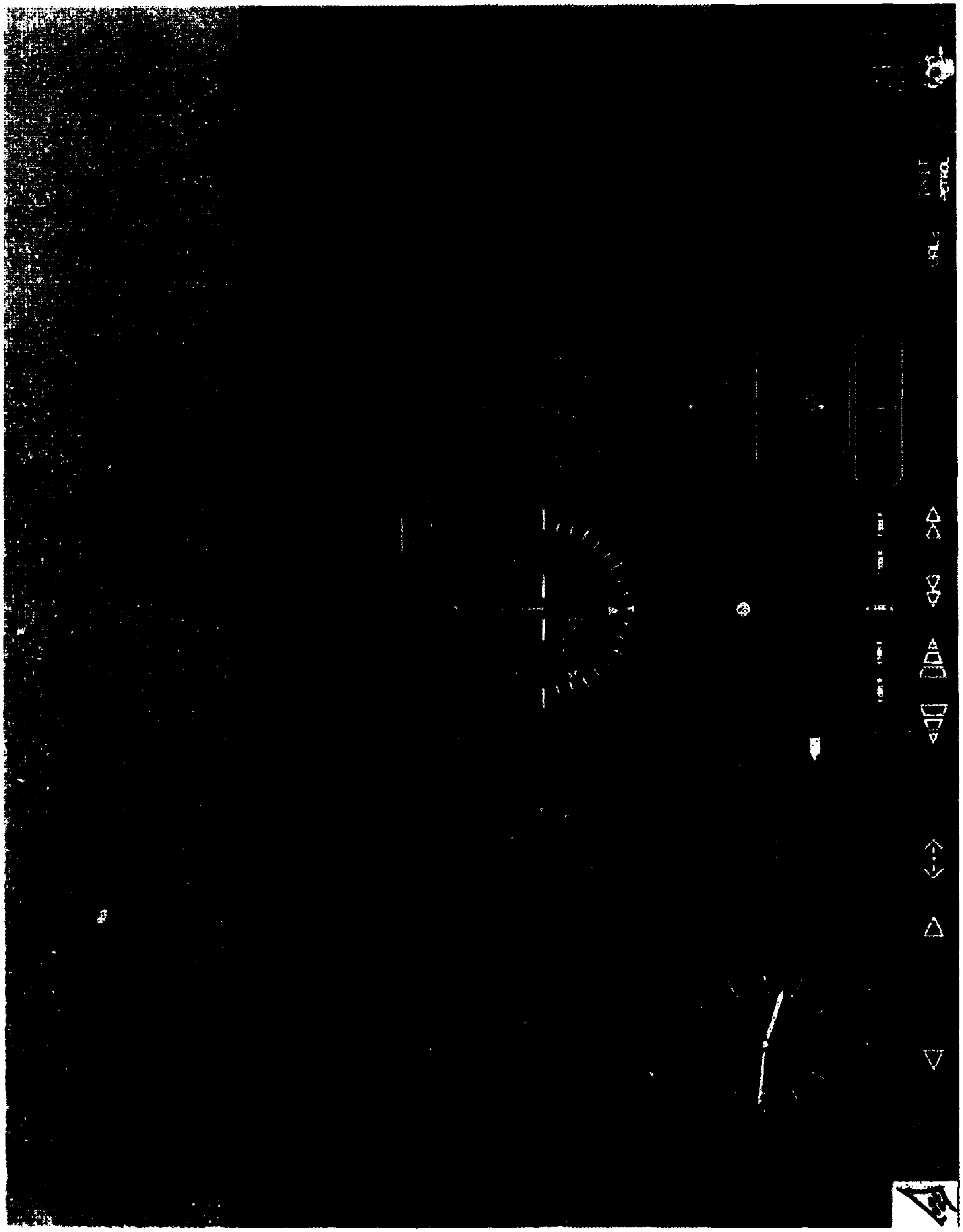


Figure 1

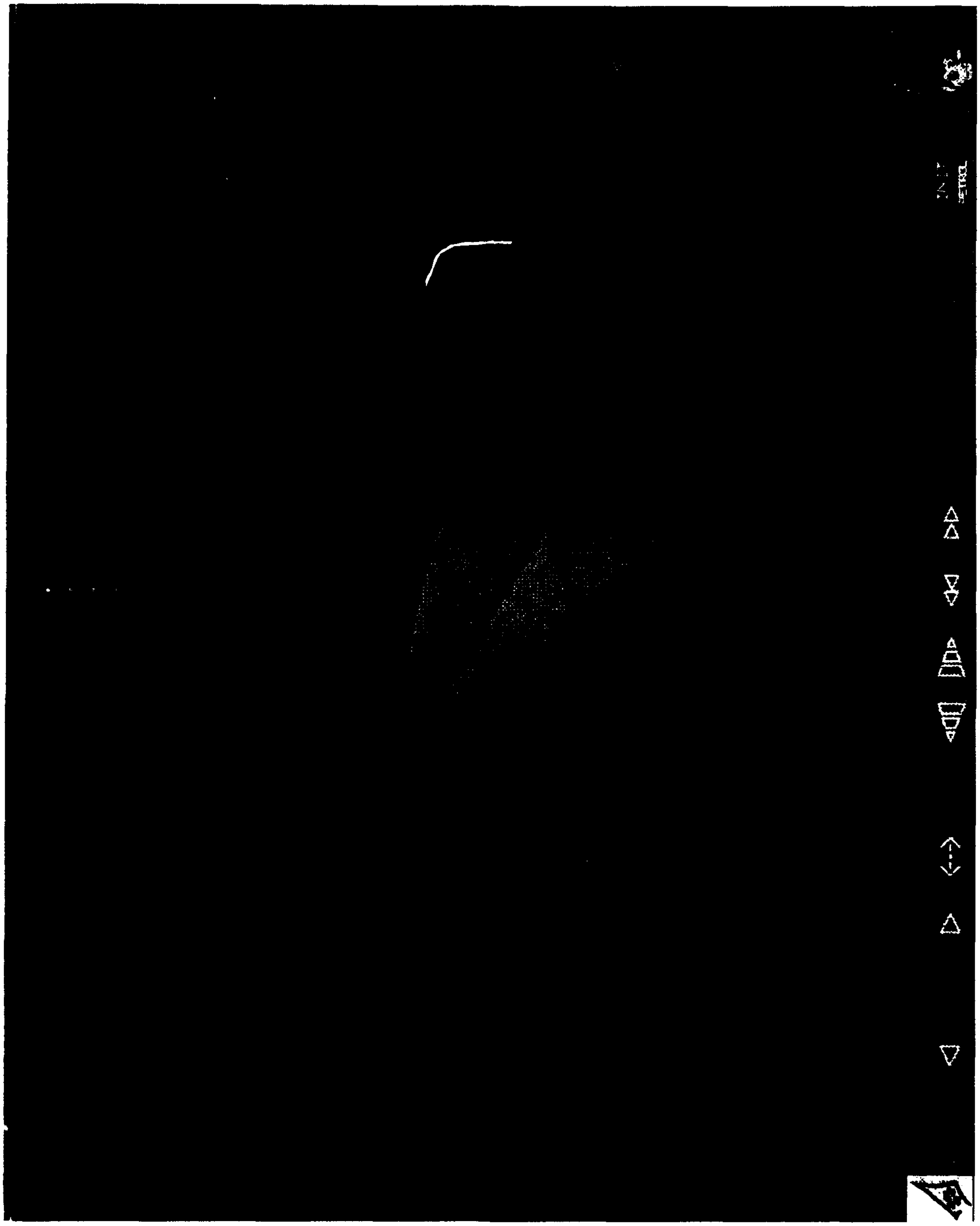


Figure 2

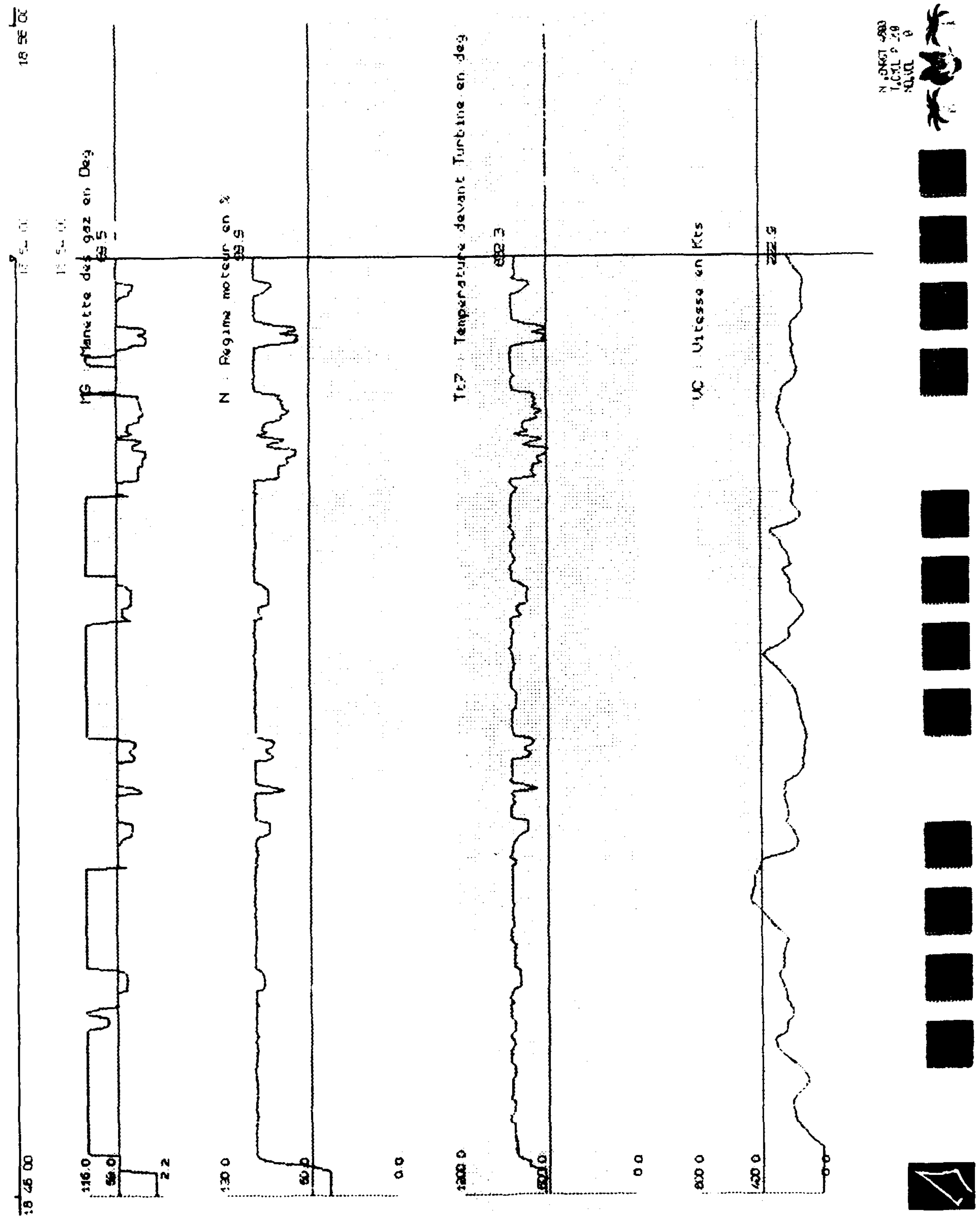
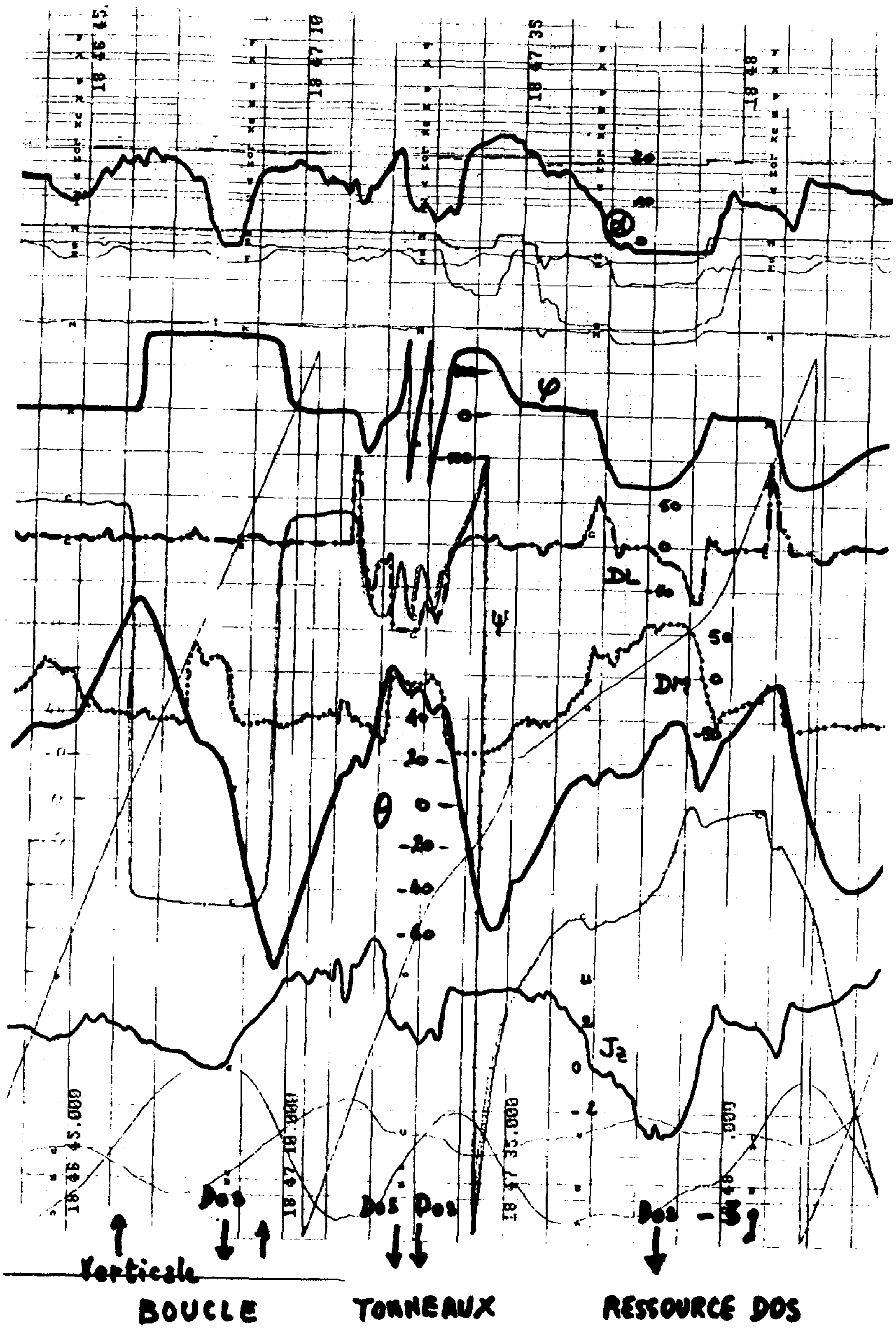

MG : Manette des gaz en Deg
N : Regime moteur en %
Tt7 : Temperature devant Turbine en deg
VC : Vitesse en Kts

Figure 3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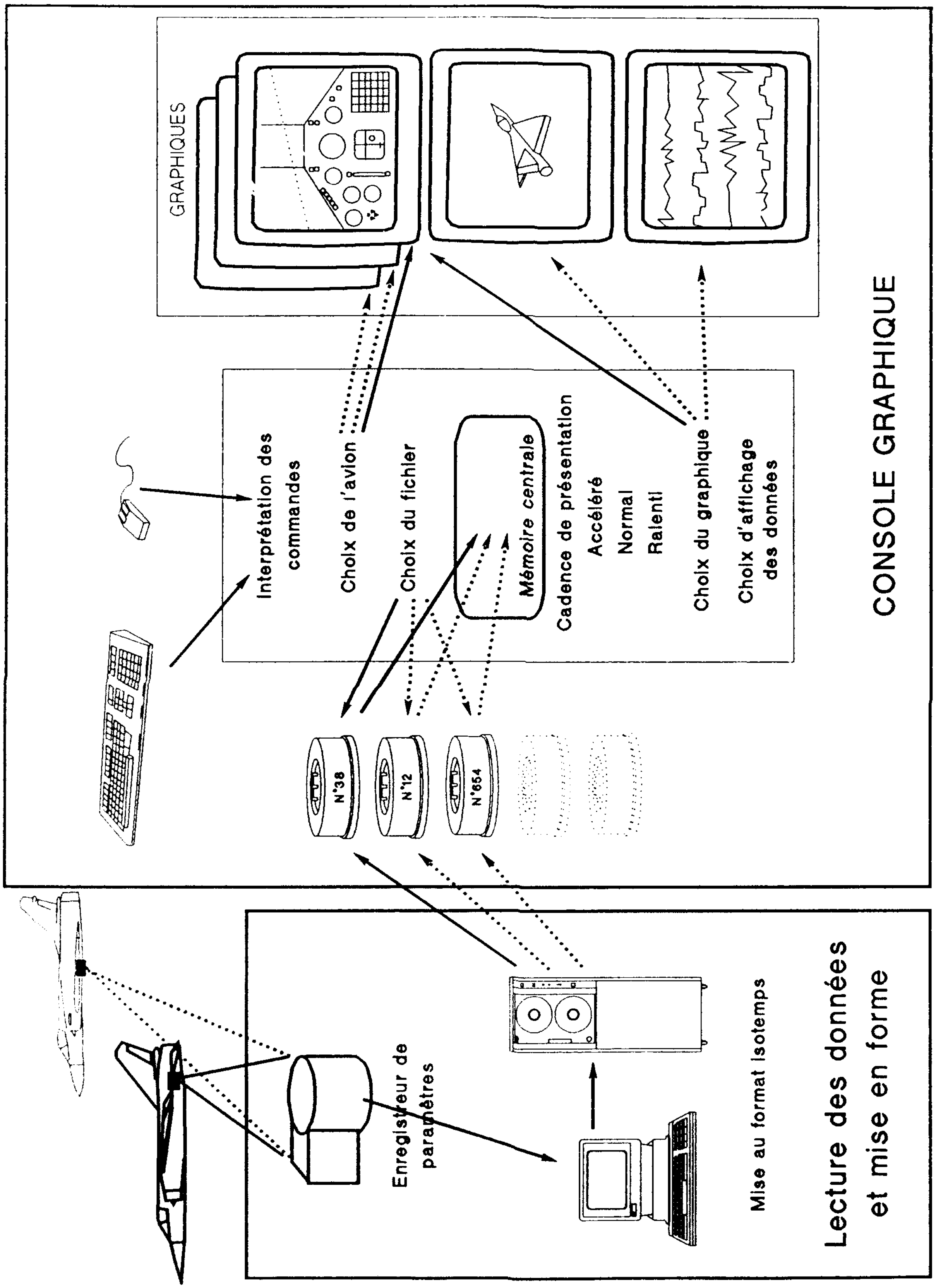
VIRAGE SERRE TONNEAU
ROCK 'N ROLL

Figure 5



GRAPHIQUES
Interprétation des commandes
Choix de l'avion
Choix du fichier
Mémoire centrale
Cadence de présentation
Accéléré
Normal
Ralenti
Choix du graphique
Choix d'affichage des données
CONSOLE GRAPHIQUE
N°38
N°12
N°654
Enregistreur de paramètres
Mise au format Isotemps
Lecture des données et mise en forme

Figure 6

ORGANIGRAMME DE LA CONSOLE GRAPHIQUE

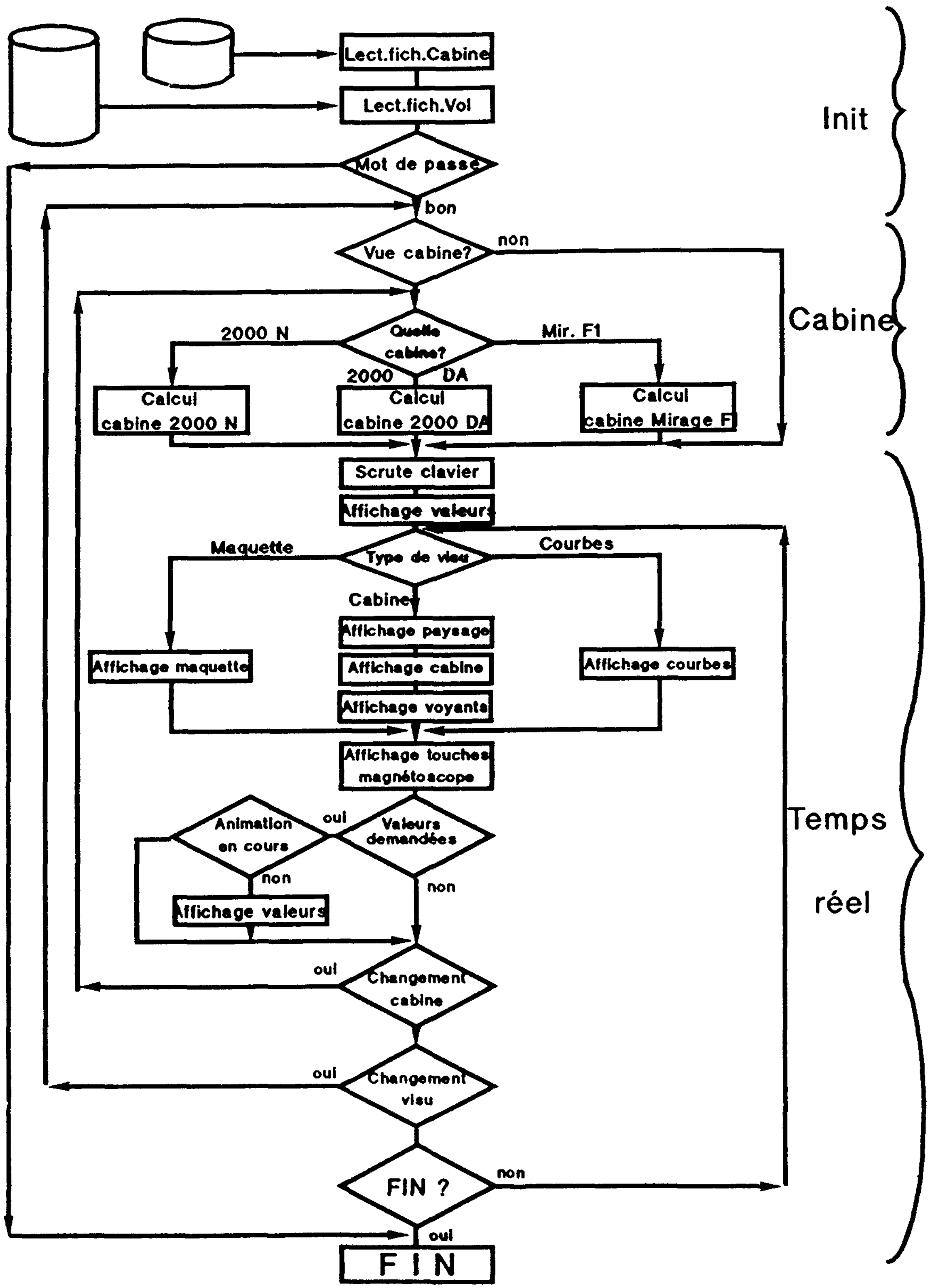


Figure 7

ASSESSMENT OF MORALE IN TURKISH AIR FORCE PILOTS WITH TWO CLINICAL PSYCHOLOGICAL TESTS

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SUMMARY

In popular understanding good morale is equal to the perception of well being, lack of distress and absence of anxiety and depression. Actually the term morale is related to anxiety and depression. The rational of this survey is to assess numerically stress levels by using anxiety and depression scores.

345 active duty Turkish Air Force (TuAF) pilots and 70 non-flying air force officers as control group, have been taken into this study. "State Trait Personality Inventory" (STPI-Spielberger) and "Zung Depression Scale" (ZDS) were applied to both groups in 1988.

As an unexpected result, the flyer group has reflected lower scores than the non-flyers. Different explanations are available but they are most likely to be related to high motivation and job satisfaction as well as ego strengths of flyers. These factors can elevate the ability to cope with stressful conditions.

It is well known that individuals, who have a steady interest and passion to fly, perceive the risks of flying as relatively low because of their high motivation. But it is very hard to preserve this motivation without disruption for a long time because fliers are subject to the same life stressors as everyone else. Pilots work on "slippery ground", eventhough they may be perceived by other to be immune from distress, fear and worries. This perception can be present even in personnel who are responsible for taking care of fliers.

Even the most resistant individuals have a "breaking point" when confronted with overwhelming stress conditions. It may be delayed, but may not be prevented. The only variable is the threshold, and any threshold may be reached given the right recipe of factors. External, internal or some combination of stressors may lead to the breaking point or insufficiency in individuals.

It is suggested the term "emotional disturbances" rather than "psychiatric disorders" should be used for these cases (1). Hidden or obvious pilot insufficiencies or emotional disturbances may contribute to either aircraft accidents or a pilot's disqualification.

Experienced pilots cost so much money to train that their disqualification is not economical. In the event of an accident, pilot and aircraft losses are described as a horrible nightmare in aviation. Poor stress coping and cumulative stress load are two important reasons for aircraft accidents (9). Therefore, the kinds of stress factors that affect the fliers or "what happens under the helmet", need to be monitored from time to time.

In fact, fliers are routinely examined psychiatrically once a year, and if necessary may be referred for re-examination. Also flight surgeons check them again every flight day. When they have a problem, they are prohibited from flying, even if they have a desire to fly. On the other hand, if they desire not to fly, regardless of their health, it is accepted by the administration because of its respect for the psychological and physical welfare of pilots. No other occupation is subject to such rigorous health checks as those given to pilots. Even so, the occurrence of stress-related accidents demonstrates that these multidimensional control mechanisms can fail at times.

RATIONAL AND METHOD

When discussing aviator stresses, there are different viewpoints among people who are involved in this field. De-emphasizing or over-emphasizing, false or true analyzing efforts and problem solving proposals may occur. The normal level or risk taking or stress load in certain flying activities is undetermined. Also the standard stress scores for certain types of aircraft and tasks are unknown.

Norms may vary from person to person. Specific issues can be evaluated by open-ended questions in a questionnaire. These kind of survey results are generally particular and individualistic. Also every questionnaire is not perfect, because building a questionnaire requires experience and multiple factors may make them unreliable.

In addition, "stress" and "morale" can be elusive concept to measure (9). In the literature stress is qualified as "loosely correlated with anxiety... furthermore depressive illness is a common reaction to stress (3). "stress has been linked to a wide variety of psychological symptoms including depression..."(5). These concepts of stress leading to anxiety and depressive symptoms support the use of standardized symptom-related rating scales such as: Raskin-Covi Diagnostic Scale, Hamilton Depression/Anxiety Rating Scale (10).

In general understanding anxiety and depression words (concepts) are not obvious rather than term morale. On the other hand morale presents a concept that is difficult to explain but it contains within it the willingness to confront adversity with tenacity, zeal, optimism and stamina (2). It can be said that a high stress load leads to poor morale. But how can high stress levels be measured especially numerically so that comparison with other groups, or changes over time can identified? The Holmes and Rahe Life Change Unit assessment scale is not useful in this kind of survey, rather anxiety and depression scales may help to more effectively determine flier's stress and morale levels.

Consequently the Zung Depression Scale (ZDS) and the Spielberger's State Trait Personality Inventory (STPI) are accepted for administration to pilots, in order to evaluate depression and anxiety levels. The results are interpreted as indicators of morale and distress levels.

Turkish Air Force pilots are referred to the Aeromedical Center (Eskisehir, Turkey), for routine examination once a year. In 1988, ZDS and STPI were applied to 345 pilots revealed no organic and psychologic complaints who passed their physical examination. These pilot group's score are compartmentalized in accordance with their bases and squadrons, so that they can be compared in terms of stress levels. The same tests were given to 70 non-flying Air Force officers as a control group. This group also was healthy and had similar ranks and ages.

These self report inventories contain 20 questions each and scores are compared by the "student test".

RESULTS

STPI scores standardized for the Turkish community, equal 38,1 in people without disease, 39,7 in those with physical diseases and 55 in those with psychiatric diseases (7). The scoring range for the ZDS follows gradually increasing symptoms of depression from 50 to 100. Less than 50 scores mean normal or lack of significant depression.

Table I shows both Air Force fliers and non-fliers are normal in terms of depression symptoms. In addition, anxiety scores are not high. Fliers are within the normal range, and non-fliers are a little bit higher than standard scores. When comparing the differences between the two groups'scores. When comparing the differences between the two groups'scores, the results were found to be statistically significant ($p<0{,}01$).

DISCUSSION

Non-fliers'living conditions seem more quiet, more steady and less risky; so one would have expected their scores to reflect less stress, except for random individual problems.

There is a significant elevation in the scores of non-fliers, both in depression and anxiety levels. This suggests that fliers are relatively happier, have better morale and feel less distress in spite of the risky nature of their occupation.

Possible reasons follow:

1. While pilot personality characteristics have been categorized and thought to be somewhat homogenous, a non-flier population against whom to compare data is more difficult to describe. However, this non-flyer group was little different. Almost all 70 people initially had graduated from Air Force College and had attended Undergraduate Pilot Training (UPT) school together with the flier group, as pilot candidates. But they were eliminated in either the medical examination phase or in the flight training phase and then assigned to non-flying duties.

In the beginning, their personality characteristics were likely to be close enough for comparison.

Over a period of time, flying duties and other military duties may create different traits in people. The non-flyer group may also have eliminated from training due to deficiencies in ability and/or lower stress tolerance levels than successful pilot candidates. Their test scores may then reflect this difference.

2. Fliers are generally more resistant to flight environment stressors; coping repertoires are larger, and ability to overcome difficulties is greater. Flight activity looks like a sophisticated play that enables them to exhibit skill, bravery and masculinity. It may serve oedipal fantasies or allow sublimation of aggressive urges, compensate inferiority and counterphobic traits, etc. Flight motivation may be related to a few known (perhaps more unknown) factors; namely joy, mastery, power, freedom, control of the environment (in order to overcome and control anxiety), obtain career goals and prestige (4,6,8).

Generally fliers are proud of their profession. People respect them because of their skills. Special flight clothes, symbols, patches, extra flight pay, promotion probabilities, adventurous lifestyle.. all of these factors may make a flier more satisfied with this job.

Thus, fliers may overcome or deny some hardships more readily than non-fliers. This is likely to be related to their ego-strengths, job satisfaction, and level of motivation. These factors are crucial in enhancing morale, especially the last two.

The main reason for this investigation was to clarify fliers' morale and subjective stress level with a took that allowed numerical scores. These scores also allowed comparison to other groups, specifically a group of Air Force officers. While this DATA is valuable, this can only be seen as the first trail of a continued evaluations of "normal" pilots to better understand fluctuations of stress levels in "routine" flying operations.

Further research may focus on specific "problem areas" identified in subsequent studies. The benefits of continued documentations of stress in aviators, lies in the application of preventive measures by active squadrons to enhance mission safety and flight performance.

ACKNOWLEDGEMENT

I would like to thank Dr David Jones for encouraging me to prepare this article with his large knowledge and experience.

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TABLE I. STATE TRAIT PERSONALITY INVENTORY (STPI) AND ZUNG DEPRESSION SCALE (ZDS) SCORES OF TURKISH AIR FORCE FLIERS AND NON-FLIERS

	n	SCORES	ZDS
Air Force Flier	345	35.52	40.05
Air Force Non-Flier	70	38.41*	44.77*

* ($p<0.01$)

737-400 at Kegworth, 8 January 1989 - The AAIB Investigation

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SUMMARY

A Boeing 737-400, jet transport aircraft, G-OBME, carrying 8 crew and 118 passengers, crashed near Kegworth, Leicestershire, on 8th January 1989. Of the 126 occupants, 47 died as a result of the accident and a further 74 suffered serious injury. This paper describes the structures and survivability investigations conducted into this accident by the Air Accidents Investigation Branch (AAIB) of the UK Department of Transport and reproduces the 11 AAIB Safety Recommendations (out of a total of 31 in the final Report) concerning crashworthiness and survivability.

This paper also describes the study performed for this investigation by the Cranfield Impact Centre, using the KRASH computer code to quantify impact pulses. The results of the KRASH work supported the AAIB recommendations in the G-OBME report and form the background to a programme at the Cranfield Impact Centre to facilitate the use of impact computer codes in aircraft accident investigations.

BACKGROUND

The increasing emphasis on 'survivability' in accident investigation contrasts with the days when the investigators concentrated almost entirely on the prevention of recurrence of the accident itself. For instance, there was a civil C47A Dakota crash in Kent in 1947 in which 8 of the 16 occupants sustained fatal injuries but the comprehensive UK AIB accident report contained just the simple statement that: "The passengers' seats had torn away at the floor anchorages. The safety belts were found still fastened and were probably being worn at the time of the crash" and made no further comment on what we would now regard as being a largely survivable impact!

For AAIB, survivability and evacuation investigations have centred in 3 areas: evacuation and survival at sea after helicopter ditchings; survival in the harsh decelerations of accident impacts; and survival and evacuation around aircraft fires. AAIB conducted an intensive investigation into the survivability at the accident to Boeing 737-236, G-BGJL, at Manchester on 22 August 1985 (ref. 1), where there was fire but no crash pulse, and the investigation into G-OBME forms the corresponding case of the crash pulse without but no significant post-crash fire. In considering the lessons of both accidents it is crucial to remember the number of accidents involving both impact <u>and</u> fire.

ACCIDENT TO G-OBME NEAR KEGWORTH

G-OBME was a 737 Series 400 aircraft and was making a single-engine approach into East Midlands Airport following a fan blade failure within the No. 1 engine in flight and the subsequent shut-down by the crew of the No. 2 engine. About 2.4 nautical miles from the runway the fan of the No. 1 engine began to break up and, with the crew unable to restart the No. 2 engine, the aircraft sank below the glideslope.

The aircraft's first impact was in a level field adjacent to the eastern embankment of the M1 motorway: it then suffered a severe impact on the western carriageway and on the western embankment of the motorway. Of the 126 occupants, 47 died as a result of the accident and a further 74 suffered serious injury (figure 1).

ORGANIZATION

When the AAIB investigation started, the author was asked to lead the structures group of the investigation and Dr Anton (of the RAF's Institute of Aviation Medicine) to lead the AAIB survivability investigation. The nature of this accident was such that these two threads of the investigation were very closely woven, linking, for instance, aircraft damage to the Injury Severity Scores (ISS) of the occupants.

A group of leading medical consultants independently formed themselves into the NLDB (Nottingham, Leicester, Derby, Belfast) study group. These doctors were drawn from the hospitals which received patients from the accident and the group was led by Professor Wallace of the University Hospital, Nottingham. Although the study group worked independently of AAIB, the sharing of a large amount of factual information was very beneficial to both investigations. The NLDB group published their own report as well as several individual medical papers, with some of their work based on a study commissioned by the group using the crash victim simulation program MADYMO.

The accident also caused considerable interest in the United States and a study group from NTSB, FAA, Boeing and the seat manufacturers participated in the AAIB investigation. This interest was generated by this being one of the first accidents to have occurred to a jet transport equipped with seats designed around the requirements of FAR Amendment 25-64: the so-called '16g dynamic test' requirements.

OBJECTIVES

The initial objectives of the structures and survivability portions of the AAIB investigation were:

i) to determine the impact sequence and to quantify the deceleration pulses,
ii) to determine the extent and sequence of the aircraft structural damage,
iii) to determine the extent and sequence of the structural damage to the occupant seating and other furnishings,
iv) to determine the extent and nature of occupant injuries and
v) to relate these to the cabin environment.

IMPACT STUDY (KRASH)

As part of the structures and survivability aspects of the investigation, it was decided to attempt a computer-based modelling of the ground impact dynamics of G-OBME. The primary objective was to refine the deceleration levels at the cabin floor throughout the impact sequence. Secondary objectives were to determine the efficacy of such a computer-based model and whether such a study could achieve useful results within the time-scale of the overall accident investigation.

The two broad groups of computer programs available for impact dynamics may be classified as:

i) 'full' finite element programs, which model a vehicle structure in detail, using only geometric and material-properties input data.
ii) 'hybrid' programs, which use a simpler library of structural elements for the model and incorporate some test-derived data for the collapse properties of key members within the structure.

KRASH is a hybrid program and has been developed specifically for the analysis of aircraft impact problems. Because of its simpler modelling, and the availability of full-scale test data from previous FAA full-scale impact tests, the KRASH program was selected and Cranfield Impact Centre was commissioned to perform the study (reference 2).

CONFIGURATION (figure 2)

For crew seating, the cockpit was configured with conventional pilots' seats, positioned on floor-mounted tracks and equipped with 5-point harnesses. The aircraft had seating for 5 cabin attendants, arranged as 2 double seats and 1 single seat, all of which were aft-facing. Both double seats were mounted on the left-hand side of the aircraft, one just forward of the forward/left passenger door and the other just forward of the rear/left passenger door. The single attendant seat was mounted just forward of the rear/right passenger door.

At the time of the accident, G-OBME was configured with 156 passenger seats in a single class cabin with a total of 26 rows of pairs of triple seats, all built by Weber Aircraft (figure 3). The seat pitch ranged from a maximum of 38 inches, for the 2 seat rows (12 and 14) next to the overwing emergency exits, to a minimum of 30 inches for row 27L. The remaining seat pitches were either 31 or 32 inches. This type of seat had been approved to TSO-C39a (the static requirements for existing aircraft type certifications) and had, in addition, been subjected to some dynamic testing on the FAA's Civil Aeromedical Institute (CAMI) track around the requirements of FAR Part 25 Amendment 25-64 (the 'dynamic' requirements).

The aircraft was equipped with a total of 30 overhead stowage bins in the passenger compartment. Of these, 26 were of 60 inch length and fully available for passenger hand baggage. The remaining two end pairs were shorter and partly used for cabin safety equipment (figure 4).

IMPACT SEQUENCE

The first ground contact was made just short of the M1 eastern embankment (figure 5), with the main landing gears touching almost simultaneously with the tail. At first impact the aircraft's attitude was approximately 13° nose up, with about 4° of right roll and 4.5° of left yaw. The actual impact velocities had to be extrapolated from the final Flight Data Recorder (FDR) readings because of the use of volatile memory buffering in this type of recorder, giving a ground speed of between 104 kts (calibrated airspeed, corrected for wind) and 111 kts (from the aircraft Inertial Reference Unit). The rate of descent was between 8.5 feet/sec (barometric rate of descent) and 16 feet/sec (radar altimeter rate corrected for terrain). These velocities combined to give an aircraft final flight path angle of between 2.5° and 5°.

The first impact detached the tail-skid and APU door and the drag loads on the two main landing gears failed both legs rearwards: the airframe remained otherwise intact. The aircraft then cut a swathe through the trees on the eastern embankment and, as it descended across the motorway, the left wing struck a central lamp standard, fracturing the standard at its base and removing the outboard 6 feet of the wing.

The second, and major, impact occurred when the nose contacted the base of the western embankment. The first contact was made by the nose wheel on the road surface followed by the nose radome striking the embankment and the engine nacelles striking the road surface. The nose landing gear failed rearwards, the nose crushed against the embankment and both engine support structures failed upwards.

There was no indication of velocity at the second impact from either the FDR or the aircraft instrumentation. It became evident during the investigation that the major factor in the deceleration pulse in the second impact was the resultant (horizontal and vertical combined) velocity at this impact. Estimates covered the range of 77 knots (from a simple first-order aerodynamic calculation) to 99 knots (from an impact analysis provided by the airframe manufacturer): AAIB concluded that the highest probability was in the range of 85 to 95 knots.

For determining the deceleration pulse transmitted to the cabin floor in the second impact AAIB considered 4 sources of information:

i) the results of a KRASH computer simulation performed by the Cranfield Impact Centre (ref. 2),
ii) calculation of the basic kinematics,
iii) the damage to the passenger and pilot seating related to previous dynamic testing,
iv) comparison of airframe damage with previous calibrated tests.

All these sources of evidence indicated deceleration levels in the second impact in excess of the pulses defined in Amendment 25-64 and the balance of evidence indicated a resultant deceleration, within the centre section, with a peak value of between 22 and 28g (figure 6). Peak deceleration in the nose section would be slightly higher, but with a shorter pulse, and the peak deceleration rather lower in the tail section.

A significant point drawn from the AAIB work on defining the impact and its deceleration pulse was the difficulty of defining the severity of the major deceleration. Such a pulse is a combination of, for instance, rise time, duration, peak deceleration and overall velocity change: none of these components provides, by itself, an adequate description of the severity of the pulse. Thus the overall velocity change of the seat dynamic tests (35 and 44 feet/second) are just as important as their associated peak deceleration levels (14 and 16g).

AIRFRAME DAMAGE

Two major structural failures of the fuselage occurred in the impact, one slightly forward of the wing leading-edge and one aft of the trailing-edge. These failures left the structure in 3 sections (figure 7).

All 3 landing gear legs and both engine supports failed, without rupturing the fuel tanks. In the case of the 2 main landing gear legs, the separations were clean and were as designed, fracturing the system of calibrated 'fuse pin' bolts which attach the main landing gears to the wing structure. The engine pylons were also designed to separate cleanly from the wing. Although both engines did separate without rupturing the wing fuel tanks, all the 'fuse pin' bolts were found intact and the structural failure had occurred within the pylon itself, approximately in the vertical plane of the forward wing spar.

The nose section sustained considerable crushing in the lower flight deck area and the belly skin disintegrated along the length of the forward passenger cabin. The floor of the forward passenger cabin was entirely disrupted (rows 1 to 9) and the stubs of the floor beams indicated that the failures aft of seat row 1 were in a forward and downward sense. The centre-section remained intact and the wings remained attached: the floor in the centre-section itself was intact (rows 10 to 17) because it is built on the wing torsion box but the flooring aft (rows 18 to 24R) of the centre-section was, again, disrupted. The tail section was almost inverted but had retained an intact floor (rows 24L to 27).

The failure pattern of the floor structure was studied in detail, both by examination of the areas of floor which had retained some integrity and by reconstructing, with the aid of individual floor beam drawings, those areas which had been fragmented. A distinctive pattern of failure emerged. The initial failures were of the longitudinal seat tracks under the inertial loading of the passenger triple-seats. The resulting displacement of the seat track members from the floor panels prevented the floor panels from reacting the longitudinal crash loads and the transverse floor beams then failed under the longitudinal and torsional crash loads, for which they were not designed, as well as from the vertical loads.

SEATING

Both pilots' seats were found still on their tracks and, despite the heavy impact damage to the flight deck area, both seats remained attached to the floor and the restraint systems were only slightly damaged. On both seats the seat pans were found at the bottom of their vertical travel and this had caused additional seat damage. Similarly, all 5 attendant seats suffered some damage but remained basically intact and attached to their respective toilet modules. All the crew members survived.

The decision was made early in the investigation to attempt to match individual injuries to individual seat damage and so, after delivery of the wreckage to AAIB at Farnborough, the cabin seating arrangement was reconstructed. This task was made more difficult because the cabin seating was single class and, during the rescue and salvage operations, a total of 38 triple seats were removed from the aircraft, generally after extensive cutting to allow the release of injured passengers. By fracture-matching of the seat pieces and identification of pieces of seat track still attached to the seats' rear attachments, the position of all the seats was (eventually!) established.

Although there was variation in the damage to individual seats, some distinctive patterns emerged (figure 8). In the forward area (rows 1 to 9), for instance, all the seats were totally separate from the floor structure but in no instance did the seat structure fail at the rear track attachment. This appeared to have been principally due to the articulation designed into the attachment to allow for the warping requirements of the new seat tests.

On the other hand, the seats in the centre section (rows 10 to 17) had remained attached to the cabin floor, with the exception of 2 individual outboard seats which had suffered complete bending failures of their horizontal front spars. There was also spar deformation in several other seats and it was the correlation of this damage to occupant injuries which enabled the medical investigators to postulate that the primary mechanism of femoral fracture was the result of the femur being bent over the horizontal front spar of the seat This was confirmed by the loads shown by the MADYMO simulation commissioned by the NLDB group.

OVERHEAD STOWAGE BINS

All the overhead stowage bins were recovered from the wreckage and their cabin positions determined. Photographs taken during the rescue operation and interview evidence from rescuers indicated that all the bins had become detached in the accident, apart from the forward bin on the right-hand side (1R), which was partially detached. The pattern of damage to the bins themselves reflected the cabin damage, with the least damaged bins in the centre and tail sections and the most damaged being those creased and crushed in the buckled area aft of the wing.

On all the detached bins the initial failure appeared to have occurred when the diagonal tie fitting pulled out of the bin upper surface (figure 9). The lateral and vertical tie-rods then failed when they were subjected to the longitudinal inertial load for which they were not designed.

INFANT AND CHILD RESTRAINTS

There was one infant on board and he was seated on his mother's lap, restrained by a supplementary 'loop-type' belt. The child was severely injured and the mother, who later died in hospital, sustained a higher injury severity score higher than the occupants of neighbouring seats. At the time of the accident there was no requirement in the UK for infant restraint on transport aircraft but the UK CAA (Civil Aviation Authority) now requires that, for take-off, landing, emergency conditions and flight in turbulence, 'all passengers under the age of two years are properly secured by means of a child restraint device': this amendment has generally been interpreted as requiring the use of the supplementary 'loop-type' belts.

The CAA has recently funded a research programme to study alternatives to the loop-type' belts and now allows the use of certain specified child-seats. However, in the UK there is no published Standard for child seats in aircraft and the onus to provide the child seat remains on the accompanying adult.

AAIB SAFETY RECOMMENDATIONS

The AAIB final report was published on 18th October 1990 (ref. 3) and it contained 31 Safety Recommendations. 11 of these concerned crashworthiness and survivability issues. In the United Kingdom, recommendations made by AAIB are generally addressed to the UK CAA (Civil Aviation Authority): the CAA are required to consider these recommendations and publish a response.

Engines:

The lack of a significant fuel release in this crash was partly due to the ruptured centre-section fuel tank being empty for this flight and the damage to the left wing-tip occurring outboard of the fuel tank. It was also due to the integrity of the wing fuel tanks further inboard, which did not rupture despite the separation of both main landing gear legs and the separation of both engines. Although the engine separations were benign, in that the wing fuel tanks were not ruptured, the structural failures occurred within the pylons themselves, leaving the 'fuse-pin' bolts in place. This raised the question as to which impact scenarios need to be examined for the engine separation case and AAIB recommended that:

> "The CAA should review the existing Joint Airworthiness Requirements concerning fuel tank protection from the effects of main landing gear and engine detachment during ground impact and include specific design requirements to protect the fuel tank integrity of those designs of aircraft with wing-mounted engines."

Seating:

From the analysis of the major deceleration impulse it was clear that the forces encountered in the second impact were considerably greater than those for which the airframe and the furnishings were designed and certificated. It is in this context that the discussion around the seat performance in ME took place.

In general the crew seating performed well and, by remaining in position, limited the crew injuries resulting from secondary impacts with the cabin interior. For the passenger area: "where the floor survived, so did the seats". The examination of previous accidents, the early dynamic testing of seats designed to the previous ('9g') static criteria and the dynamic testing of this model of passenger seat all indicated that fewer injuries occurred in this accident than would probably have been the case with passenger seats of an earlier generation. However, some structural failures of the seats did occur, such as the front spar failures in the overwing section of the fuselage, and the AAIB recommended that:

> "The CAA should actively seek further improvement in the standards of JAR 25.561/.562 and the level of such standards should not be constrained by the current FAA requirements."

The performance of the passenger seats in G-OBME also supported the case for fitting the improved seats into all newly-manufactured aircraft coming onto the register and retrofitting existing aircraft, at least on a seat replacement basis. The AAIB thus recommended that:

> "The CAA should require that, for aircraft passenger seats, the current loading and dynamic testing requirements of JAR 25.561 and .562 be applied to newly manufactured aircraft coming onto the UK register and, with the minimum of delay, to aircraft already on the UK register."

The medical investigation surrounding this accident suggested considerable scope for improving the detail design requirements for aircraft seating. In this light, the AAIB recommended that:

> "In addition to the dynamic test requirements, the CAA should seek to modify the JARs associated with detailed seat design to ensure that such seats are safety-engineered to minimise occupant injury in an impact."

As for alternative seat designs, any change would clearly have to be founded on a firm basis of research and development, including questions of compatibility with the rest of the cabin, the level of passenger acceptance and protection in a wide range of impacts. Little of this research has taken place in recent years and the limited use of rearward facing seats in military transport aircraft has not answered the questions. The AAIB recommended, therefore, that:

> "The CAA should initiate and expedite a structured programme of research, in conjunction with the European airworthiness authorities, into passenger seat design, with particular emphasis on:
> (i) Effective upper torso restraint.
> (ii) Aft-facing passenger seats."

Cabin floor structure:

The investigation indicated that the floor strength was, in fact, considerably higher than the 'static 9g' certification requirement. The pattern of failure in G-OBME, however, showed that relatively minor engineering changes could significantly improve the resilience and toughness of aircraft cabin floors and take fuller advantage of the improved passenger seats, particularly for out-of-plane loading and in providing multiple load paths.

Future designs of cabin floor should certainly have to take account of dynamic loadings to ensure that the seats, and other floor-mounted furnishings, remain in place in realistic impact cases. It is also reasonable that, at some point in the future, this should also apply to further production of existing designs. The AAIB recommendation thus read:

> "The certification requirements for cabin floors of new aircraft types should be modified to require that dynamic impulse and distortion be taken into account and these criteria should be applied to future production of existing designs."

There is wide scope for research into the feasibility of a significant increase in cabin floor toughness beyond the level of the current JAR/FAR seat requirements. A further recommendation covered this:

"The CAA should initiate research, in conjunction with the European airworthiness authorities, into the feasibility of a significant increase in cabin floor toughness beyond the level of the current JAR/FAR seat requirements."

Infant and child restraints:
The argument for child seats in motor cars has been well-established for over a decade. It can be argued that the supplementary loop-type belt provides some advantages over simple lap-holding of infants but it cannot provide an equivalent level of survivability to that provided for the adult passenger. The AAIB recommendation was that:

"The CAA implement a programme to require that all infants and young children, who would not be safely restrained by supplementary or standard lap belts, be placed in child-seats for take-off, landing and flight in turbulence."

The present regulations are still a long way from bringing about the universal use of child-seats. To do this, it is logical that the onus of provision should be placed on the airline. There are clear advantages for an airline in only having to train its cabin staff to deal with the use of one type of child-seat, optimised for the airline operation, and in not having to deal with child-seats incompatible with the airline's passenger seats.

In the meantime, to promote the effective use of child-seats and to put operators in a position to provide child-seats themselves, the AAIB recommended that:

"The CAA expedite the publication of a specification for child-seat designs."

Overhead stowage bins:
All but one of the overhead stowage bins became detached in the impact and they did so in a very uniform manner. with the initial separation of the diagonal tie from the upper surface of the stowage bin and the consequent failure of the lateral and vertical ties when the bins moved forward. Confirmation of this failure mode was that the only bin not to have separated entirely from its fuselage attachments was 1R, the only bin at which forward motion was restricted by the presence of a substantial cabin bulkhead. It was not possible to determine the actual mass or distribution of passenger belongings in the overhead bins but the results of a 1981-82 CAA survey indicated that the manufacturer's figure (3 lbs per inch of bin length) was generously conservative and that the actual loading on G-OBME was about 33% of the placarded mass.

Quite apart from the injuries caused by the bins, their presence in the cabin did impede the evacuation and there is a clear case for a substantial increase in design load factors and for features (such as the incorporation of flexible mountings) to ensure that cabin 'items of mass' would be restrained against realistic crash pulses. The AAIB recommended:

"The certification requirements for cabin stowage bins, and other cabin items of mass, should be modified to ensure the retention of these items to fuselage structure when subjected to dynamic crash pulses substantially beyond the static load factors currently required."

There was also evidence that some of the bin doors opened during the last moments of flight, before the first impact. The inadvertent opening of overhead stowage bins has long been a problem, especially in turbulence, and some airlines now fit bins which incorporate secondary latching. The AAIB recommended that:

"The CAA consider improving the airworthiness requirements for public transport aircraft to require some form of improved latching to be fitted to overhead stowage bins and this should also apply to new stowage bins fitted to existing aircraft."

As a postscript to the overhead bins, this type of bin was the subject of a subsequent series of instrumented dynamic tests conducted by the Transport Research Center of Ohio on behalf of the FAA. The mode of attachment failure identified was the same as in G-OBME. And in the first half of 1992 the US National Transportation Safety Board (NTSB) published recommendations from the MD81 accident at Stockholm in December 1991, in which a number of bins failed. These recommendations recognised the limitations of purely static load tests for certification.

CAA RESPONSE
On 23 October 1990 the United Kingdom's CAA (Civil Aviation Authority) published a summary of their follow-up action on this accident (ref. 4). All 11 of the AAIB recommendations detailed above were accepted by the Authority.

FURTHER WORK - 'AIRCRAFT ACCIDENT INVESTIGATION TOOL' (AAIT)
The use of the KRASH computer program as a part of the impact study in the G-OBME investigation was judged by AAIB to have been successful. This was largely due to the helpful attitude of both the airframe manufacturer and the FAA, under whose auspices the KRASH code was developed.

The study was not ideal, however, and did highlight a number of areas for improvement of the simulation process, both in the operation of the crash dynamics codes themselves and in the creation of the aircraft model. These would enable impact simulations to be run in a more timely and cost-efficient manner.

Following proposals from Cranfield Impact Centre, therefore, the MoD and AAIB are funding a development programme, spread over 3 years, to provide a usable tool for the analysis of aircraft impacts. This is provisionally called the 'Aircraft Accident Investigation Tool' (AAIT).

CONCLUSIONS
This accident highlights three thorny old realities of airworthiness codes:-

1) The airworthiness regulators have been able to attack the problems of seating in aircraft cabins. But these improvements can only be fully effective if the floor can keep the seats apart and the other massive objects within the cabin can be kept away from the occupants and from their escape routes.

2) The full weight of the current airworthiness code is only fully applied to the clean sheet of new type certifications. After that it's the murkier and more arbitrary world of derivatives and retrofit!

3) However good their intentions, <u>nobody</u> can legislate for good design and this is as true for crashworthiness design as for any other. The best we can hope for is a level playing field, tended by active-but-sensible regulators with twin passions for aviation and aviation safety!

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4) 'Follow-up Action on Accident Reports: Accident to Boeing 737-400 G-OBME near Kegworth on 8 January 1989'; Civil Aviation Authority, Gatwick; 23 October 1990

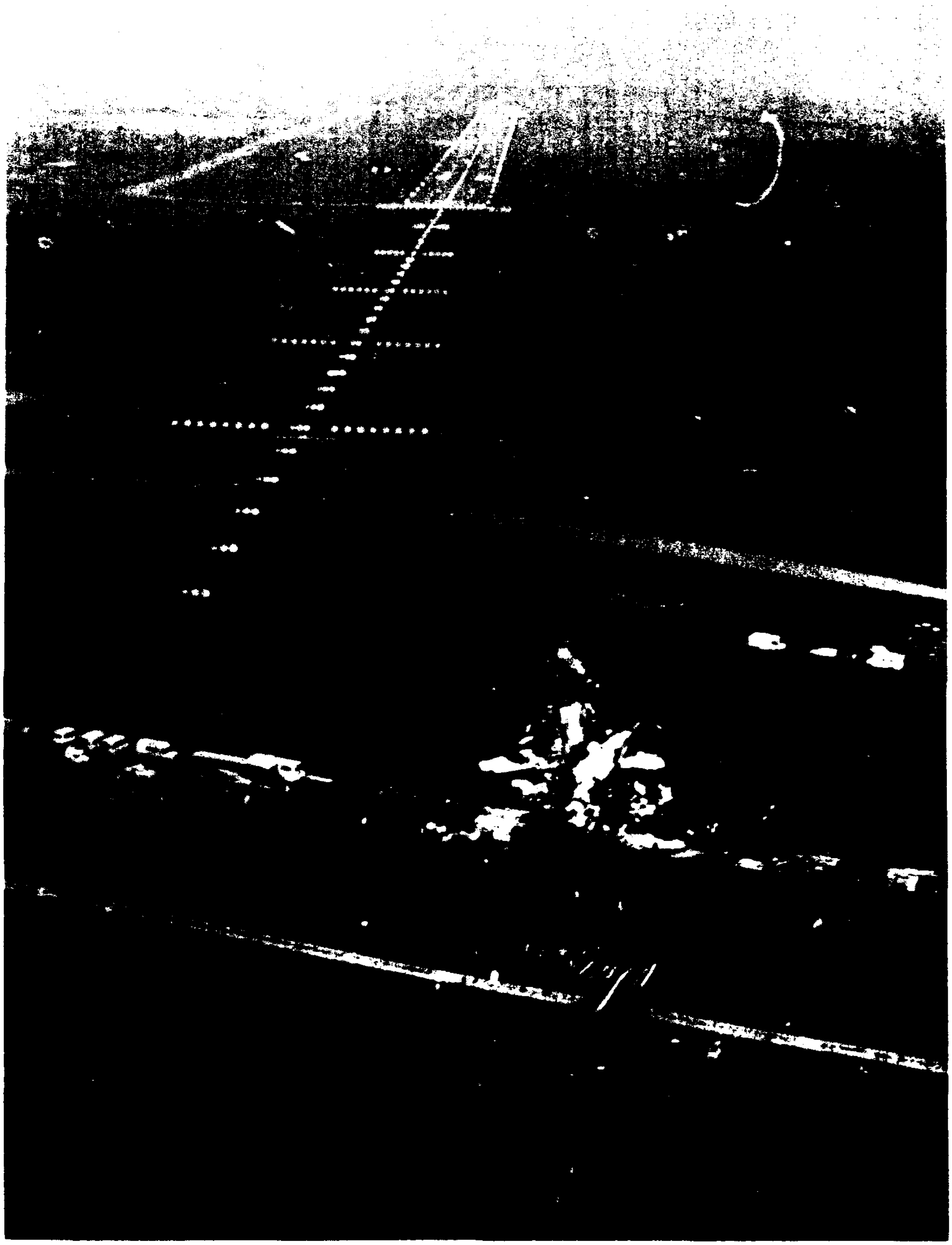

Figure 1 - Crash site of G-OBME

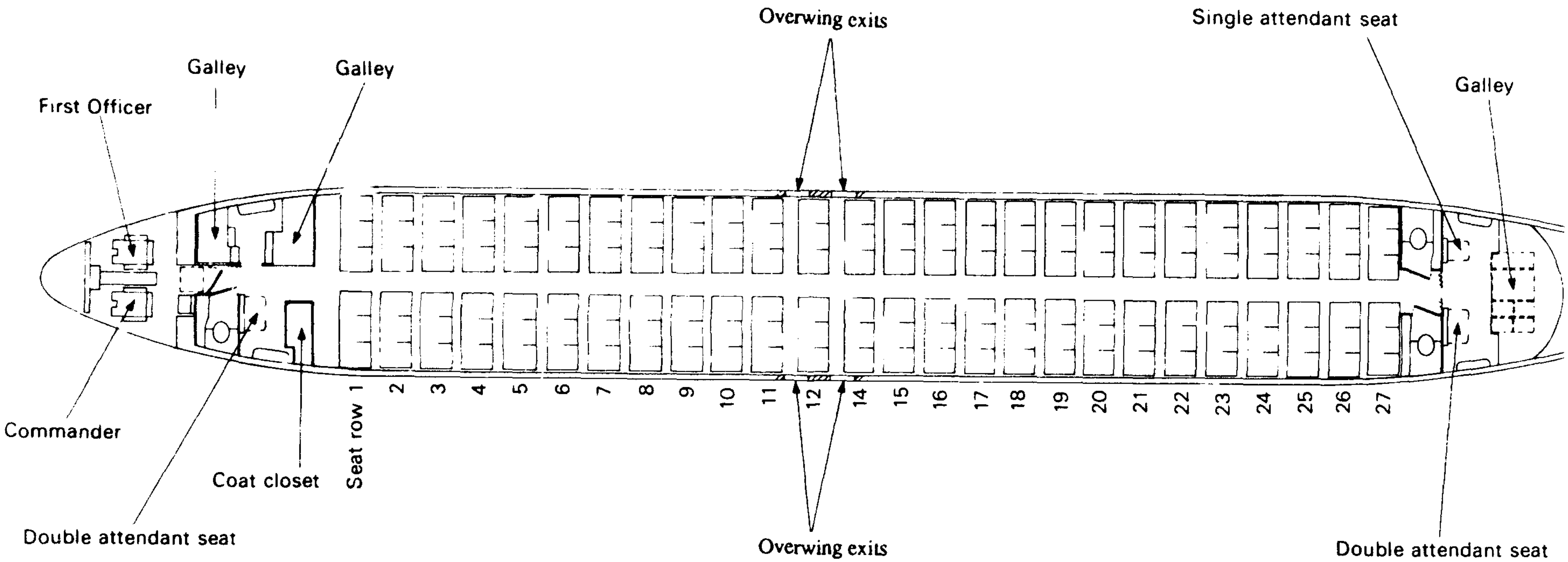

Figure 2 - G-OBME seating configuration

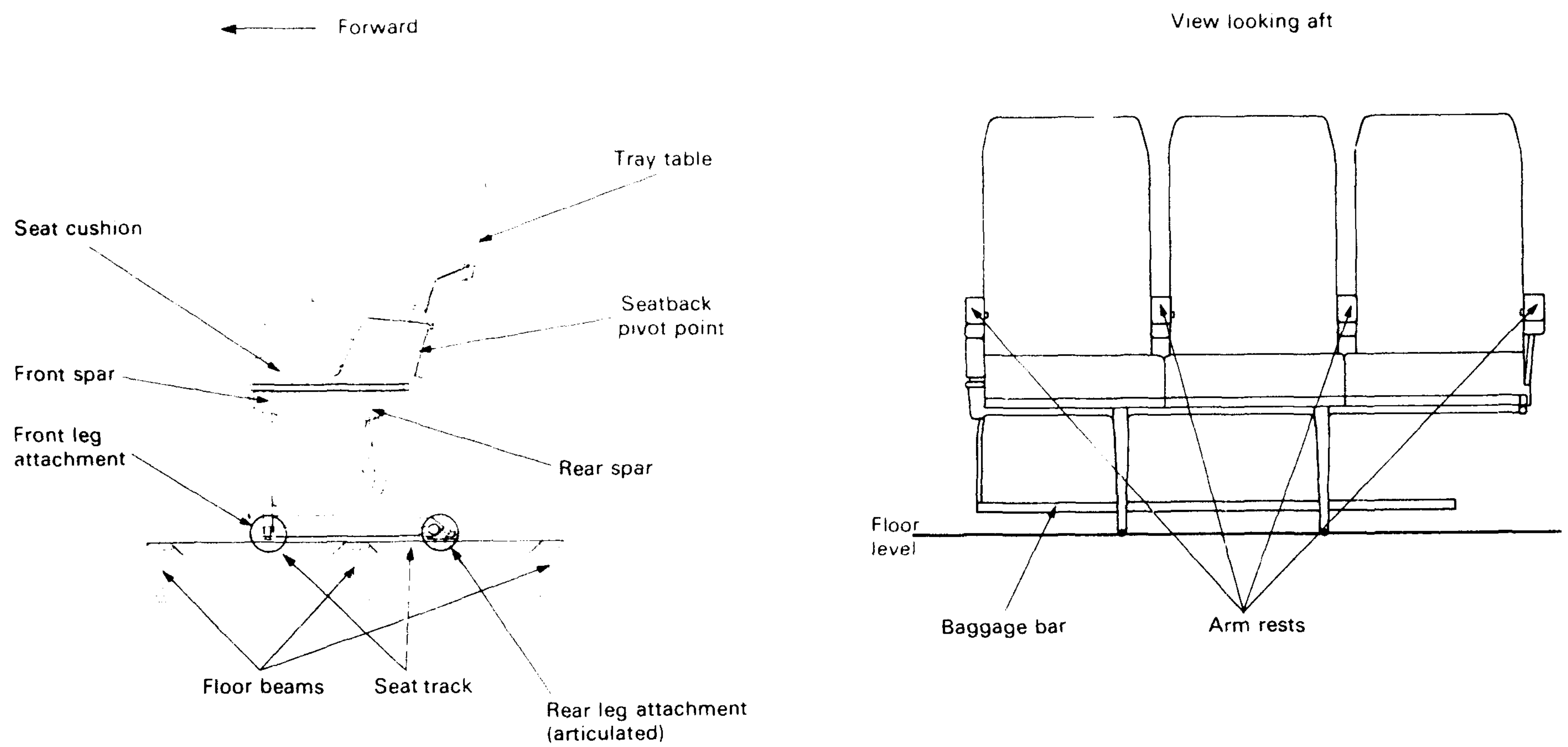

Figure 3 - Passenger triple seat (G-OBME)

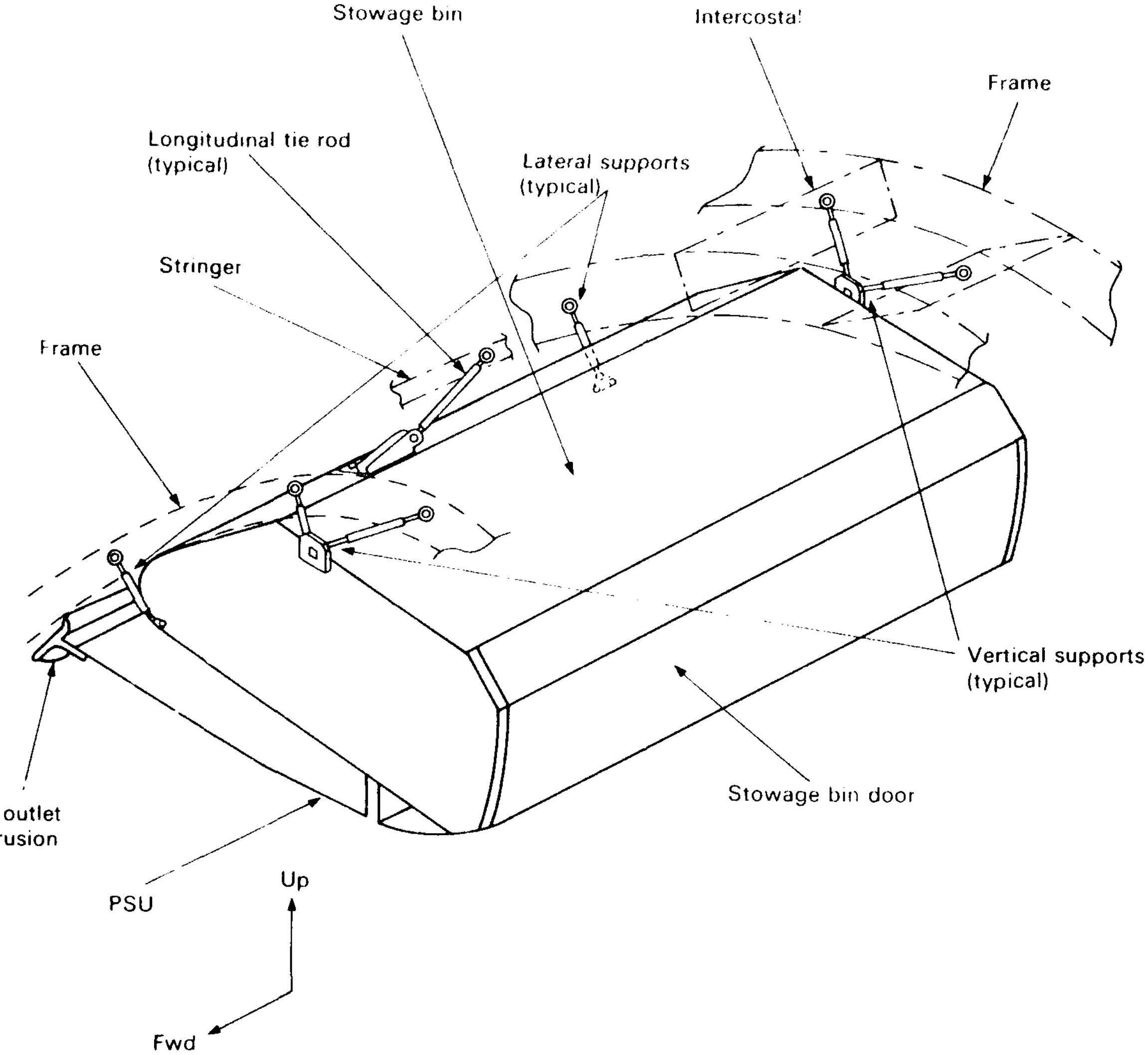

Figure 4 - Stowage bin attachments

Figure 7

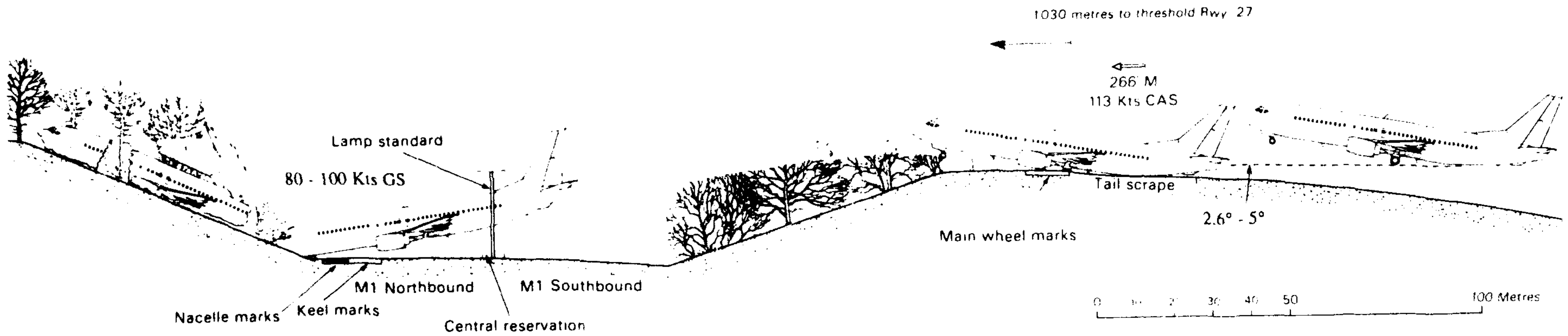

Figure 5 - G-OBME impact sequence

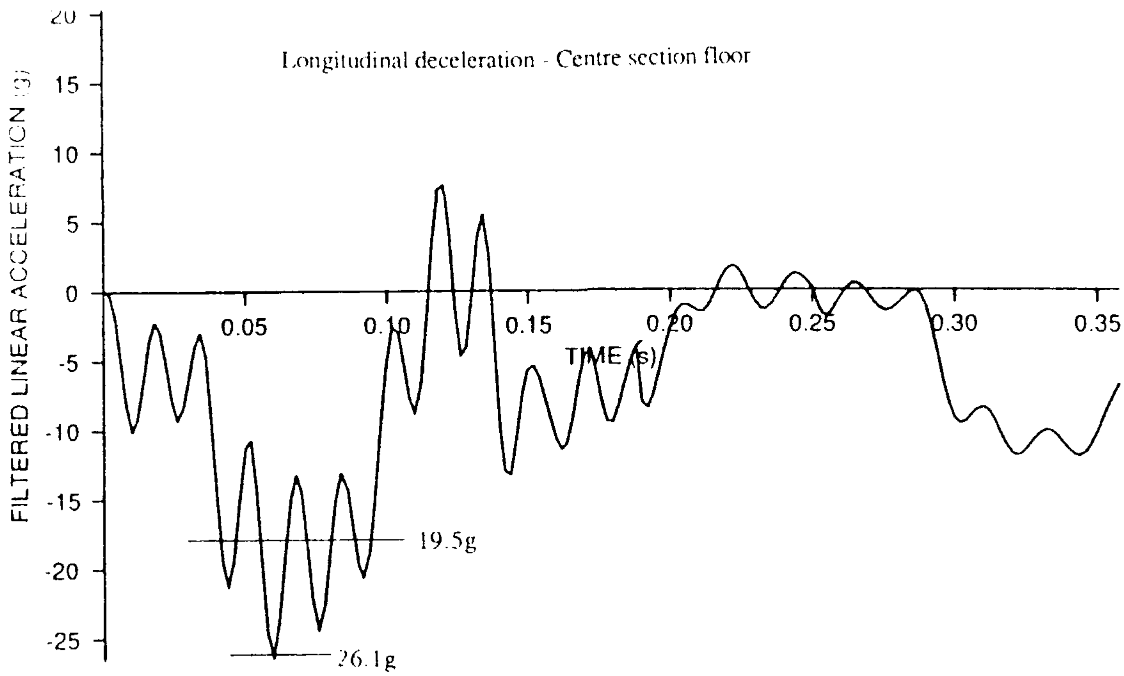

Figure 6a - KRASH simulation (longitudinal deceleration)

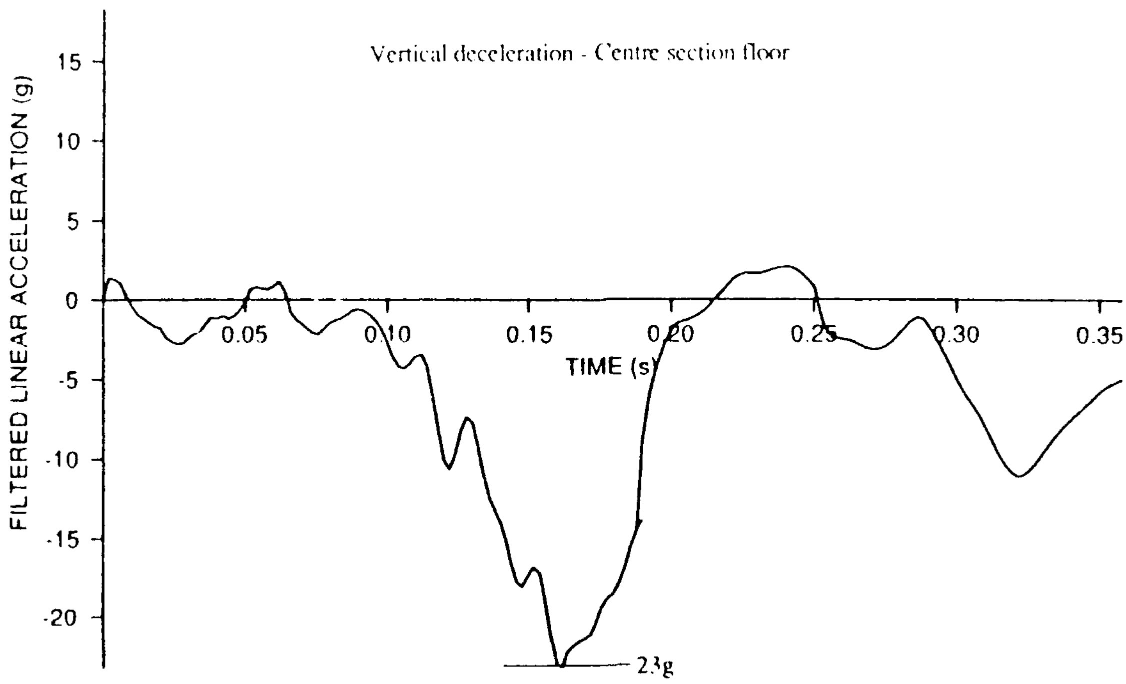

Figure 6b - KRASH simulation (vertical deceleration)

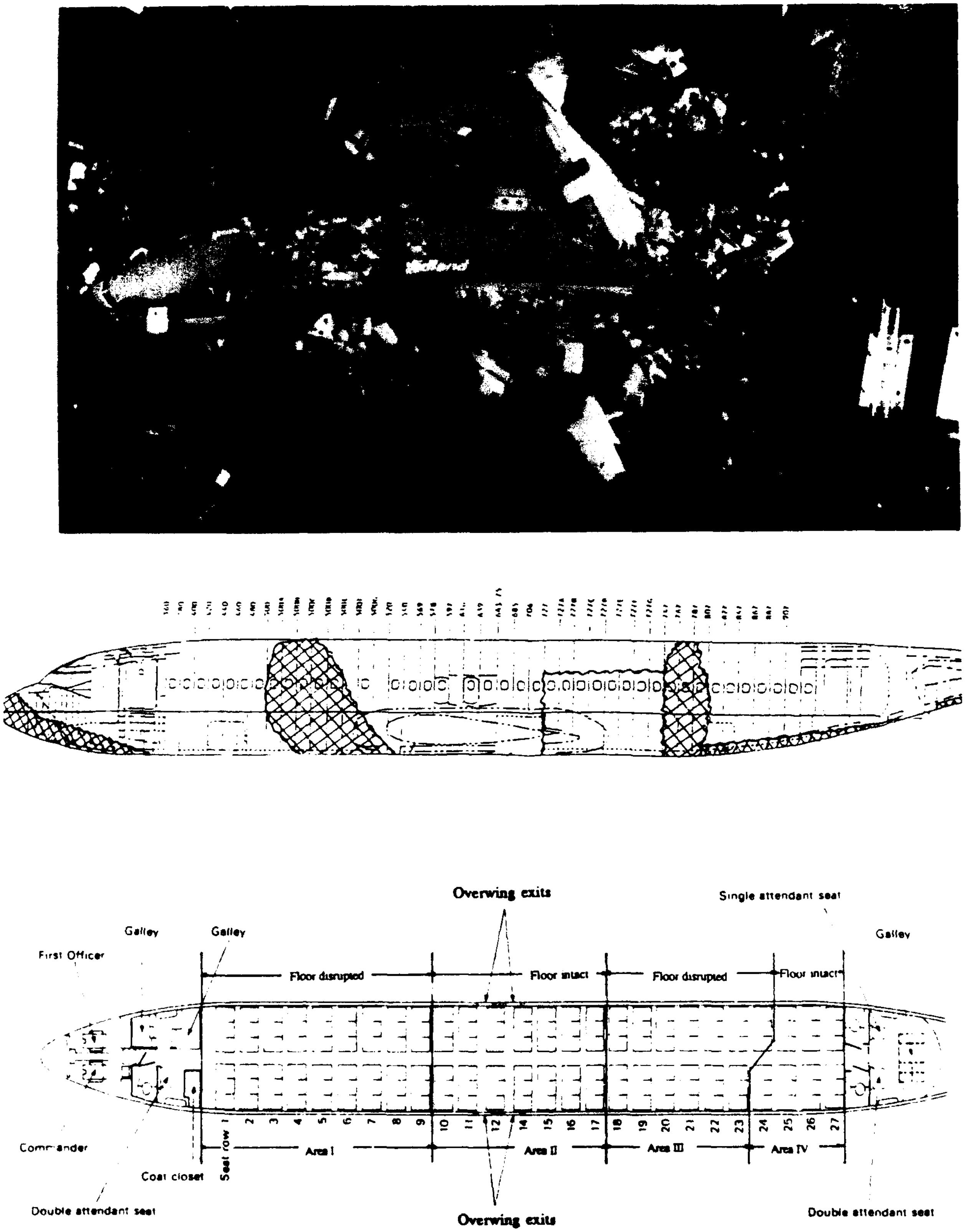

Figure 7 - G-OBME structural disruption

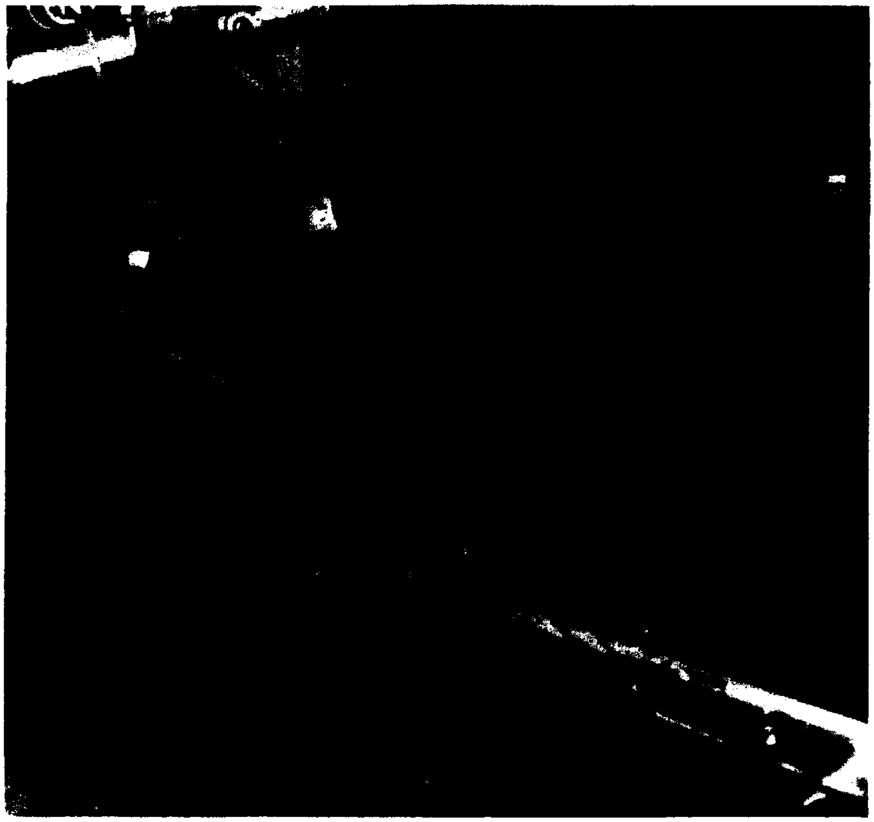

Figure 8a - Seat track and seat 3L (forward cabin)

Figure 8b - Floor beam at station 460 (forward cabin)

Figure 9a - Stowage bin attachments (G-OBME)

Figure 9b - Stowage bins (G-OBME)

OCCUPANT KINEMATICS SIMULATION OF THE KEGWORTH AIR ACCIDENT

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SUMMARY

The use of computer simulation in the investigation of the crash of the Boeing 737-400 at Kegworth has highlighted the importance of the technique in aiding the accident and medical investigations.

The analysis has shown the importance of adopting a full brace position for crash landing thus offering significant protection against injury.

The major value of the study has shown that a unique and definitive estimation of the occupant kinematics and the effects on the crash victims are possible for an aircrash.

1. INTRODUCTION

Historically, crash victim simulations have been performed using anthropomorphic test dummies in conjunction with sled and controlled impact demonstrations. The use of such devices in the reconstruction of aircraft accidents are costly and time consuming, particularly with regard to the variation in pitch, roll and yaw.

Within the last decade, data preparation for large structural analysis computer models have enabled prediction techniques to become a useful tool in tne study of structural impact behaviour. Recent advances in the use of mathematical simulations have also enabled the replication of the test dummy in a crash environment.

Mathematical models and computer simulations have been developed in order to predict the response of the body to high accelerations. This has been developed by the automotive industry to simulate the response of the occupant to a vehicle impact.

The simulation of the human being or test dummy, like other complex dynamic systems, can be represented mathematically by considering the body as a system of elements linked by rotational or translational joints. The stiffness characteristics of the joints are correlated with test. The ensuing motion of the system can, therefore, be calculated by solution of the Newtonian or commonly the Lagrangian equations. In crash victim simulations these equations are nonlinear since the forces acting on the elements can vary with displacement and time. Accordingly, computer models provide a means for solving the differential equations depicting the motion of the body.

The impact biomechanics of the passengers of the Kegworth air accident of 8 January 1989 was reconstructed using computer simulation. The objective of the study was to examine the causation and mechanisms of injuries sustained.

An analysis of the behaviour of the occupants during the accident was considered important to maximise the knowledge on survivability issues. A study group which consisted of orthopaedic surgeons, engineers, and other specialists involved in the treatment of survivors, known as the Nottingham, Leicester, Derby, Belfast (NLDB) team was formed to collate the injury data pertaining to the accident. Detailed information was collected about the survivors and the deceased. The data obtained was used to correlate the injuries sustained with the biomechanical forces predicted by the computer simulation.

A mathematical dynamics modelling program, MADYMO(1), was used to predict the injury levels sustained in the impact. The program comprises of two and three dimensional versions. The two dimensional version was used as there was no lateral acceleration involved in the accident. Post-processing was undertaken using MADPOST(2).

The Kegworth analysis consisted of a computer simulation of the motion, acceleration and force histories sustained by the occupants. These have been correlated with injury data. The analysis was restricted to those positions where the seats were retained in the aircraft. Where catastrophic failure of the fuselage and floor occurred, there was loss of survival space and a further understanding of the detailed mechanisms involved could not be undertaken.

The aircraft sustained an impact lasting 2.2 seconds. This commenced with the initial tail skid impact on the east side of the motorway, until the aircraft came to rest in three sections, on the embankment on the west side.

Some seats were retained in the nose section, mostly crew, and also in the tail section. The latter over- rode the central section, coming to rest upside down. The centre box section was the area of the aircraft best preserved, and was chosen for the simulation. The analysis was therefore most applicable between row 10 and row 20, that is, the overwing area.

A survey of structural damage to the aircraft seats and floor was carried out. In the overwing area the floor was intact and the seats had remained in position. Examination of the outboard seats of the triple row, showed deformation of the seat pan and the front spar depressed on the unsupported end.

2. MODEL DEVELOPMENT

A single occupant from whom a fairly comprehensive set of data was known, was selected for the study. This was to permit a correlation study to be made. The occupant chosen for the correlation was seated in row 15, directly behind the emergency exit over the wing. The occupant assumed a brace position.

Studies on a sister aircraft were used to determine a probable brace position of the occupant. This was supplemented by the anecdotal evidence of the survivor. The latter was represented by a Hybrid III dummy dataset, Figure 1.

The simulation comprised of two seat rows with a 32 inch pitch. The front seat held a second, supplementary, 50th percentile occupant. This was for the purpose of creating the correct response and contact environment for the primary occupant. In front of the second occupant a bulkhead was modelled to provide an additional restraint for the front occupant.

Most of the seat backs have been designed such that if a small force was applied in the forward direction they would collapse. The configuration of this aircraft also contained non-breakover seats. Thus, with row 15 directly behind the emergency exit the seat backs of the row in front, 14, were of the non-breakover type. The computer model was thus set up to represent the variation in seat back torque.

Inspection of the aircraft after the crash showed many locked seat backs had suffered total bending failure, thus the model was set up such that a breaking torque was required to fail the seat back.

3. OCCUPANT ANALYSIS

Although there was contact between the tail skid and the ground on the east side of the motorway, the acceleration levels were small, approximately 1G. The tail skid impact is estimated to have had only minor effects on the occupants, from a kinematic perspective. Although the duration of the impact was for a period of 2.2 seconds, the occupant simulation was run for a period of 1.4 seconds, beginning at the instance when the aircraft was in horizontal flight over the motorway. This embraced all the significant events giving rise to the forces sustained by the occupants.

3.1 Brace Position Analysis

The computer model which was developed, accurately predicted those injuries sustained by the occupant being studied. The occupant experienced a double impact with the seat back in front. Head and arm contact occurred between the facing seat back. In the case of the 'breakover' seats, the acceleration was sufficient to release the seat backs before occupant contact. In the case of the emergency exit "non-breakover" seats, the impact of the occupant caused structural failure of the seat back frame.

A detailed assessment of the injuries sustained by the occupant in row 15 was compared with the computer predictions and is described below:-

3.2 Facial Lacerations

The forehead of the simulated occupant contacted the table of the seat in front. Head Injury Criteria (HIC) (3) of just under 300 were predicted, thus facial lacerations would be expected although it is unlikely that serious head injury would have occurred.

In the accident, the site of the head contact was clearly identified by witness marks on the seat back and confirmed the analysis. An indentation mark on the top left hand side of the seat back was thought to have occurred due to elbow strike. This was followed by head strike against the horizontal bar, and the lower portion of the seatback. Additionally the levels of facial injury were also as expected. The occupant did not lose consciousness. This was commensurate with a head injury criterion of about 300.

3.3 Iliac Crest and Upper Thigh Bruising

The occupant in row 15 sustained iliac crest and upper thigh bruising. On impact, the occupant was thrown forward and rotated around the lap belt. Belt loads of about nine thousand Newtons were predicted which would have caused bruising around the iliac crest. During the rebound phase of the simulation, the occupant moved up and rearward, the belt slipped down the upper legs causing bruising on the outer thighs.

3.4 Lower Limb Injuries

The occupant seated in row 15 sustained right knee bruising. From the kinematics, Figure 2, slight contact was observed between the knee and the seat in front. It was known that the seat structure deformed significantly on the right hand side of the body which would have caused the body to twist, pushing the right knee forward into the back of the seat in front.

Clinical assessments of the patients showed few soft tissue injuries around the knee in those passengers seated in this region of the aircraft. This was well predicted by the computer simulation with femur axial loads in both the braced and unbraced occupants well below the accepted limit of 10 Kilonewtons. This suggested that significant knee contact with the seat in front had not occurred. Further clinical reviews showed that the majority of femoral fractures had taken place in the central seat of the triple row where the lateral spar was supported by the seat legs. Where the spars were cantilevered, they have exhibited bending failure thus resulting in energy absorption and consequently, no femoral fractures.

The computer model predicted flailing of the lower limbs and contact with the seat in front, when the lower leg was positioned forward of the knee joint, Figure 3. The simulation of the brace position showed that should the lower leg be kept ten degrees rearward of the vertical flailing of the legs would not occur and no tibial or foot contact would take place with the seat in front.

4. UPRIGHT POSITION ANALYSIS

Many of the passengers in the aircraft did not assume a brace position, and remained seated upright. The injury levels sustained by these occupants were examined.

The simulation of the upright occupants utilised fiftieth percentile Hybrid III dummy datasets seated in two rows. Unlike the situation for the braced, where a single, well documented occupant was selected for correlation purposes, an equivalent upright occupant could not be identified for close study. Nonetheless, several similar occupants were examined on a more general basis.

The computer predictions of the injuries sustained were found to be consistent with injuries of the survivors. Head injury criteria, circa 1000, were consistent with concussion. Contacts representative of pelvic and lower limb injuries were predicted.

Medical records of the NLDB team showed that there was an increased incidence of unconsciousness due to concussion for those passengers who assumed an upright position.

A comparison of the upright occupant simulation with the brace position showed considerable differences in results. Significantly higher HIC, thorax, femur and pelvis injury levels were obtained. The simulation, Figure 4, indicated a higher degree of penetration of the occupant into the facing seat back with increased head, and chest accelerations. Severe rotation of the knee and foot joints were also apparent. These were attributed to the increased relative velocity of the upper body before striking the facing seat back.

Two further configurations were modelled to investigate the effect of lap and shoulder restraints and rear facing passengers in an aircraft accident such as that at Kegworth.

It is important to note that the assessment of the three point belted occupant was made with a standard seat. The retractor and shoulder belt anchorage were located on the fuselage of the aircraft. The rear facing seated occupant was also analysed using the same standard seat design, however, the seatback was constrained in order to stop the seatback from failing.

The results presented in table 1 show the percentage comparisons and indicate the following:-

Taking the results of the brace position as the baseline values, the HIC value for the upright occupant has increased by 250%. Whereas, for the three point belt and rear facing analysis there is a decrease of 5% and 45% respectively.

In observing the chest accelerations, the result of the upright occupant has increased by 77%. For the three point belt a decrease of 3% is obtained, whereas, for the rear facing position an increase of 35% has occurred. However, it must be emphasised that the latter is well within the standard injury limit of 60G as specified in Federal Motor Vehicle Safety Standard (FMVSS)208. The increase was due to the seat back being constrained from moving rearwards. This could be reduced by the introduction of a stroking device at the seatback or rear seat legs.

For the pelvic loads, the upright occupant shows an increase of 49% which is likely to cause fracture. This fact was also confirmed by the NLDB team, for those occupants who remained upright suffered pelvic fracture. For the three point belt and rear facing seats an increase of 11% and 4% were observed.

A reduction in belt load of 58% was obtained with a rear facing seat. The load obtained was due to the rebound of the occupant against the belt. The seat leg loads, which were extracted from the interface with the aircraft floor, show a small increase in load for the rear facing seats.

The femur axial loads for the upright occupant showed an increase of 45%. A decrease of 14% and 5% were observed for the three point belt and rear facing positions.

The result of the femur vertical force for the brace position showed higher loading than the other parameters considered. It is important to note that a decrease of 65% in the femur vertical component for the rear facing seat was observed.

The load on the fibula was highest with the rear facing seat. The increase was due to contact against the front seat spar. This could be reduced by the introduction of an energy absorbing calf support at the front of the seat.

The results of the foot loads showed that the highest loads obtained were observed with the upright occupant. This was as a direct result of leg flailing.

5. CONCLUSIONS

The upright occupant simulation demonstrated significantly higher HIC, thoracic acceleration and pelvic injury levels, with a slight increase in femur axial loading. The upright position kinematics indicated a high degree of penetration of the of the head of the occupant into the facing seat back with increased head, chest and knee contact. However, the proximity of the knee to facing seat back was insufficient to cause major injury. The simulation has also highlighted the degree of rotation which has taken place at the knee and ankle joints. A significant discovery was also made using the simulation, in the adoption of a new brace position, as illustrated in Figure 5. It should be noted from this figure that the lower limbs are inclined slightly rearward of the vertical to reduce foot and lower leg injuries.

The computer simulation was able to confirm and predict the clinical findings of increased head injury in those occupants who did not assume a brace position. The absence of knee contact as demonstrated by soft tissue injuries around the knee was also predicted. This, conclusively, demonstrates that the reconstruction of impact biomechanics using computer simulation is a valid technique.

The occupant simulation of the three point belt analysis, Figure 6, showed that no head contact occurred against the seat back in front. However, tibial contact took place with significantly reduced loads. Reductions in femur and belt loads were also obtained.

The simulation with the standard constrained rear facing seat showed that neck hyper-extension and fibula contact took place, Figure 7. These occurrences may be reduced by providing a higher head rest and calf support on the seat. The assessment of the results shows that reductions in HIC and femoral loads were obtained, although it is expected that the HIC level will increase with a higher seat back.

The major value of the computer simulation was to show, for the first time, that a definitive estimation of occupant kinematics and the effects on the victim was possible for an aircrash.

6. RECOMMENDATIONS

The correlation of the brace position was extremely good considering the multi-variable, nonlinear nature of the analysis models. The correlation was against one crash, studying other crashes is recommended.

The importance of adopting a brace position has been demonstrated, Figure 5. The adoption of this position should be drawn to the attention of passengers prior to every flight. This is far more relevant than the routine demonstration of life jackets.

The trend in results of the upright position suggest the injury levels are more severe than those of the brace position. The injury levels obtained have shown that the upright position is not to be recommended.

Three point belts offer major improvements in the levels of femoral and pelvic injuries, due to improved kinematics and load distribution. Such installations should be considered for small commuter type aircraft.

Rear facing seats reduce the levels of injury criteria and should be recommended for use in passenger aircraft. The seat back must be strengthened and increased in height. An energy absorbing calf support should also be introduced on the front edge of the seat.

Regulations should control both femur bending and axial compressive loading, rather than axial loading alone. Presently, only axial compressive loading limits are specified.

The analysis used in the simulations utilised an additional occupant seated in the row in front to simulate the forward contact environment, that is, a twin row analysis. The effect of the occupant seated behind the primary occupant should be assessed.

Work should be conducted to assess the occupant kinematics against regulatory standards with direct correlation with sled testing in order to improve aircraft seat design.

The use of crash testing to predict aircraft accidents is costly and time consuming, particularly in accident investigation. The degree of pitch and roll is not readily reproduceable. Such parameters are easily investigated using computer simulations. This has been successfully demonstrated in its application to the Kegworth M1 aircrash.

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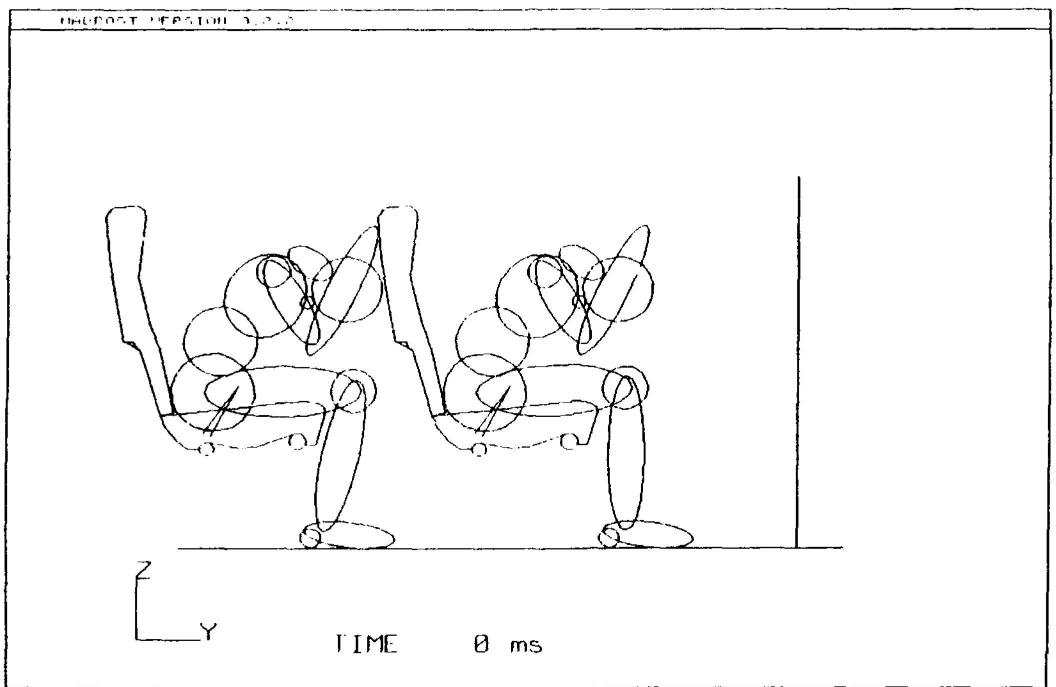
Parameter	HIC @ 36ms	Max Head Accel (m/s^2)	Max Chest Accel (m/s^2)	Femur Axial Load(N)	Femur Vert Load(N)	Belt Load (N)	Seat Front Leg(N)	Seat Rear Leg(N)	Pelvis Load (N)	*Tibia Load (N)	*Foot Load (N)
Brace	278	534	332	2330	2720	9441	19284	20346	5394	0	0
Upright	974 (+250%)	798 (+49%)	586 (+77%)	3367 (+45%)	1342 (-51%)	8798 (-7%)	16547 (-14%)	20821 (+2%)	8024 (+49%)	1152 -	930 -
3 Point Belt	266 (-5%)	462 (-14%)	321 (-3%)	1995 (-14%)	1688 (-38%)	7778 (-17%)	19205 (-0.4%)	19581 (-4%)	6005 (+11%)	1560 -	711 -
Rear Facing	152 (-45%)	369 (-31%)	448 (+35%)	2220 (-5%)	961 (-65%)	3967 (-58%)	20136 (+4%)	19664 (-3%)	5597 (+4%)	1807 -	0 -

Results for Brace,
Upright, Three Point Belt and Rear Facing Occupants - Parametric Study

TABLE 1

Note: *Contact loads against seats only.



Braced Occupant Model

FIGURE 1

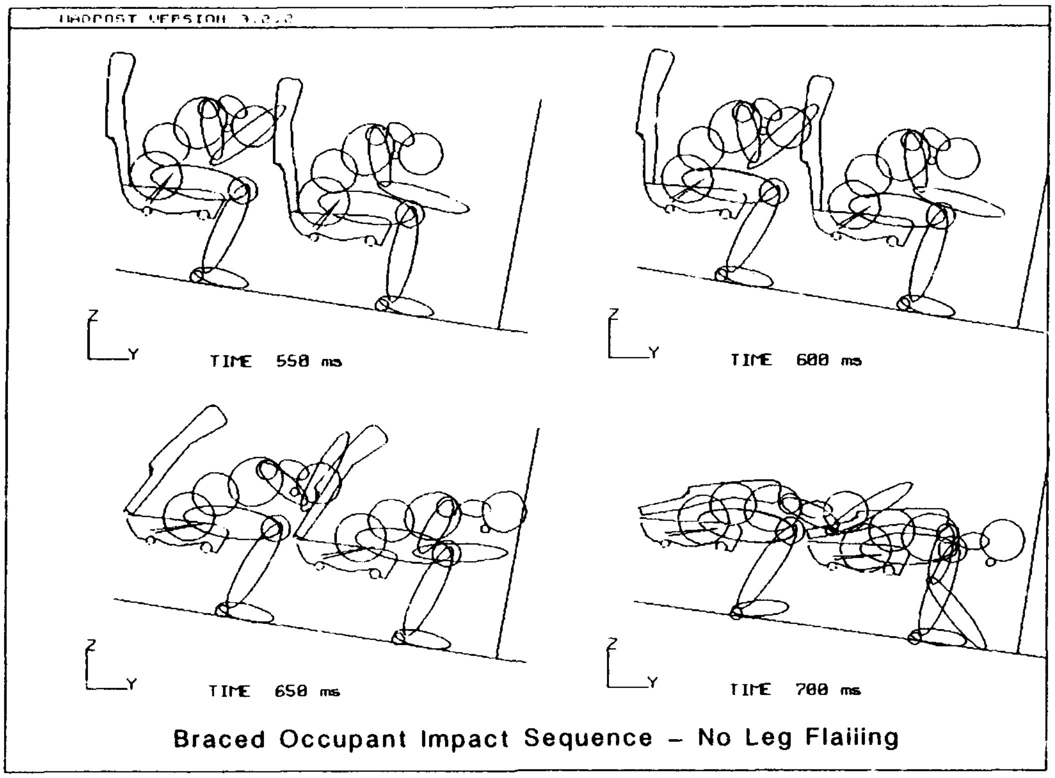


FIGURE 2

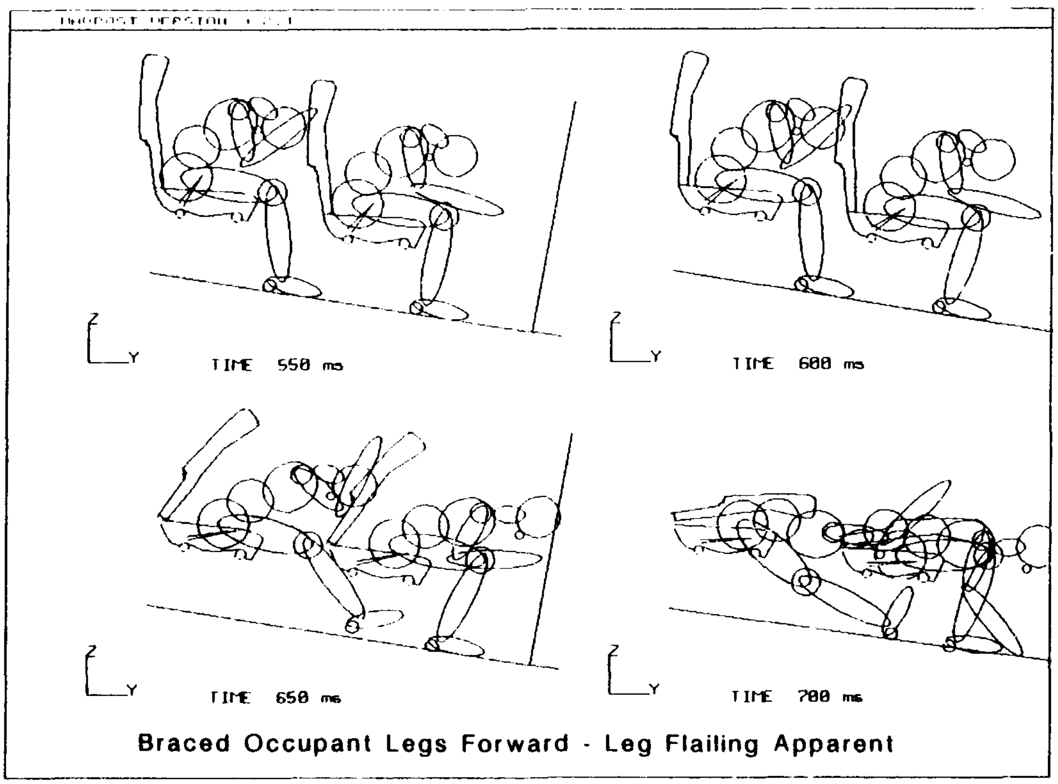
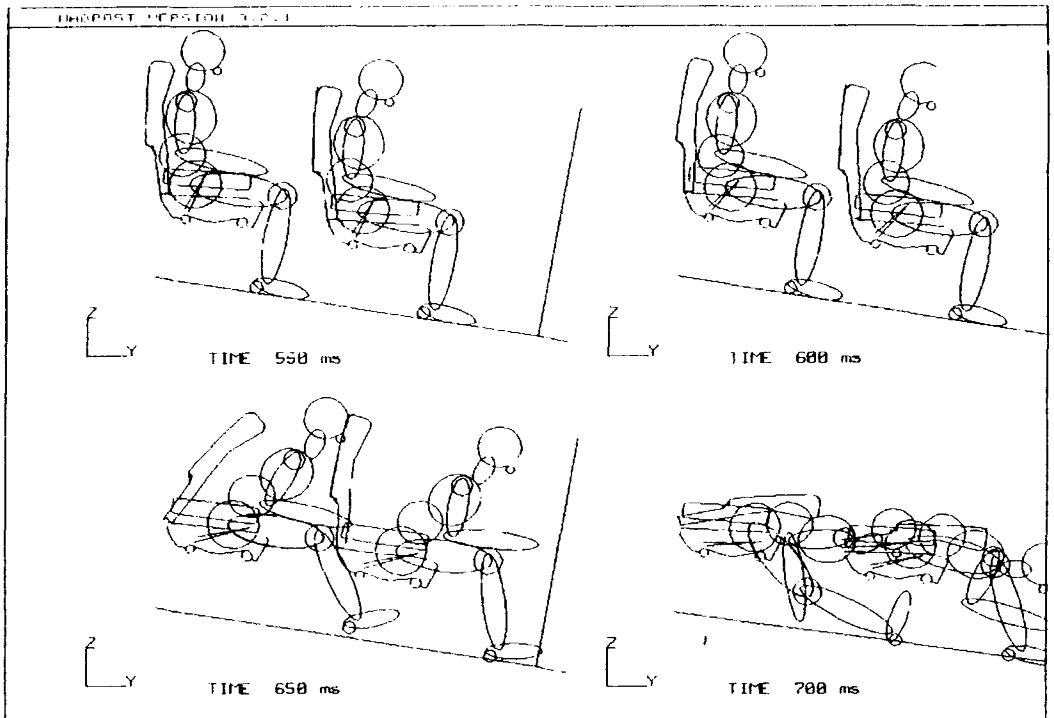
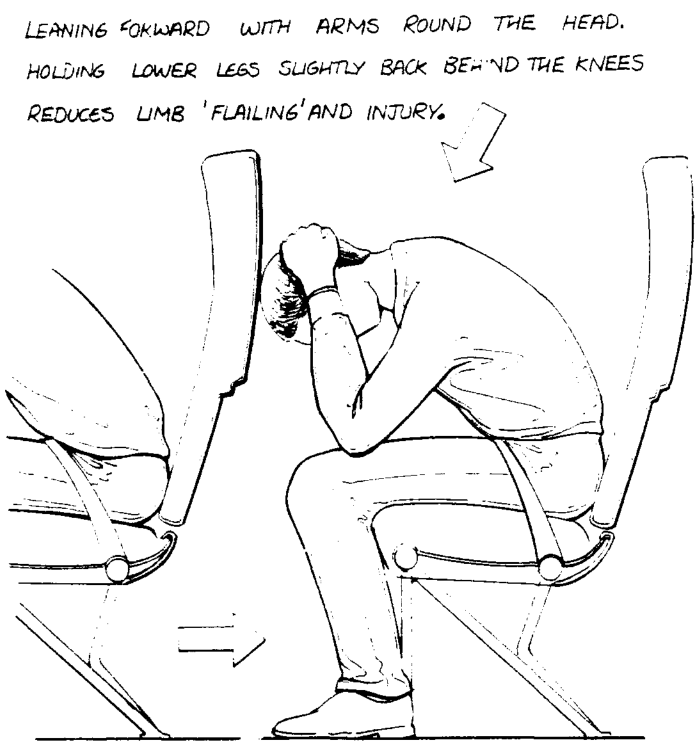


FIGURE 3



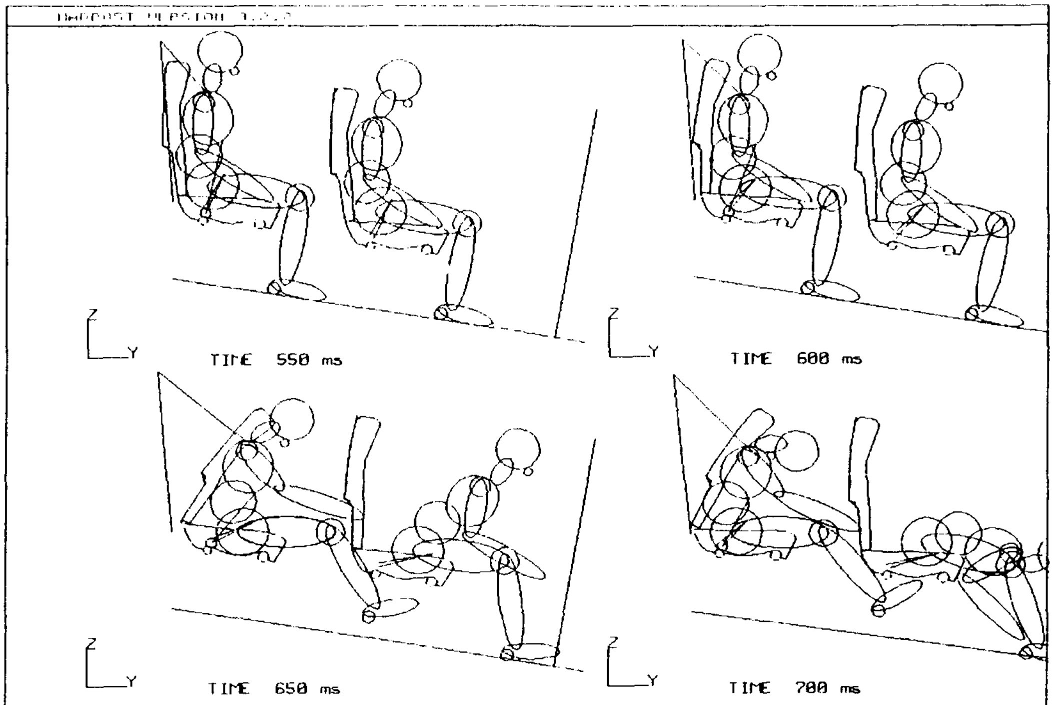
Upright Occupant Impact Simulation

FIGURE 4



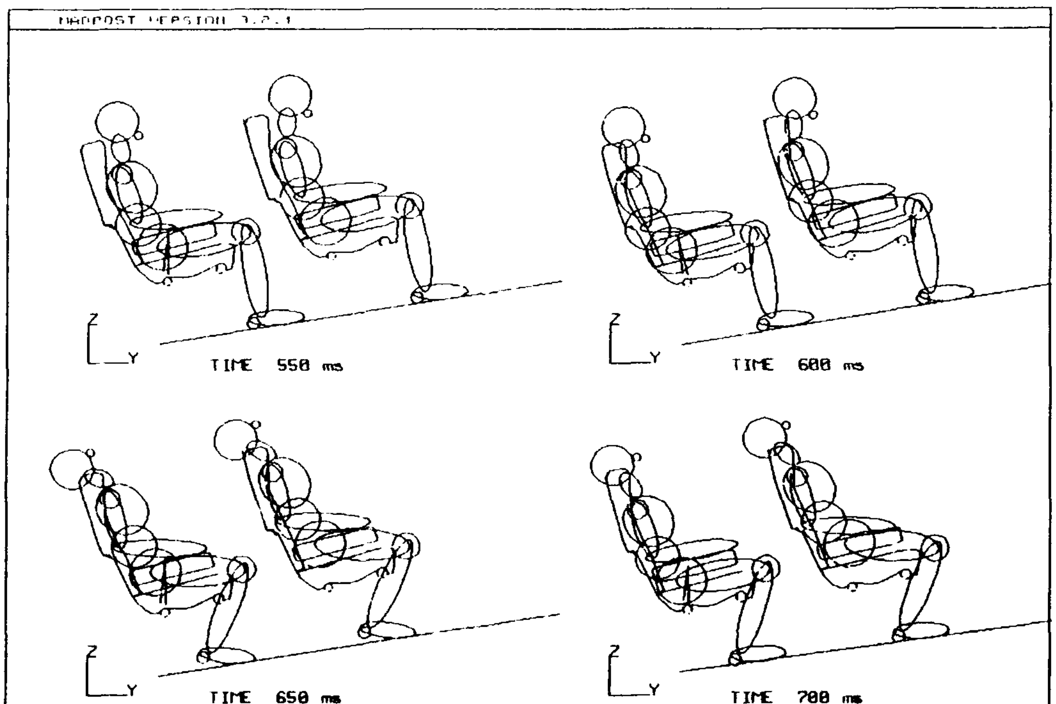
RECOMMENDED BRACE POSITION.

FIGURE 5



Three Point Belted Occupant Impact Sequence

FIGURE 6



Rear Facing Simulation with Standard Seats

FIGURE 7

CAN INJURY SCORING TECHNIQUES PROVIDE ADDITIONAL INFORMATION FOR CRASH INVESTIGATORS?

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SUMMARY

The Abbreviated Injury Score (AIS) and Injury Severity Score were calculated for all passengers and crew of the M1 Kegworth aircraft crash. Regional scores were significantly higher in nonsurvivors than survivors of the impact. Mortality and ISSs were found to correlate with the structural damage sustained by the aircraft. The use of injury scoring has highlighted variations in the severity of injuries sustained by occupants involved in an impact aircrash. This information has demonstrated that other factors in addition to the force of the impact were involved in the causation of injury, such as structural integrity, attempts by occupants to protect adjoining passengers, being struck by loose objects and rear facing seats.

1. INTRODUCTION

Injury scoring as a means of classifying the extent of trauma has a long history. The Abbreviated Injury Scale (AIS) is an anatomical threat to life scale that has been accepted world-wide as the system of choice for assessing the severity of road related impact trauma (14). However the majority of impact injury patients die because of more than one injury. Injuries that in themselves would not be life threatening could have a significant effect on mortality when combined with other injuries.

Baker et al. (2) devised a system, the Injury Severity Score (ISS) as a means of assessing multiply injured patients. Injury Severity Scoring has become an established scoring system for survival prediction and trauma audit. It is an index of anatomical injury, but takes no account of the physiological or psychological effects of trauma. The score has been found to be useful as a predictor of mortality, survival time, hospital length of stay and disability (5). This has now led to a definition of a patient with "major trauma", as a patient who scores an ISS of sixteen or more points. An ISS of 16 is predictive of a 10% mortality (3).

At 8.26 pm. on Sunday January 8, 1989 a British Midlands Boeing 737-400 airliner crashed whilst attempting an emergency landing at the East Midlands Airport, England. The aircraft sustained two impacts; a minor impact on the east side of the M1 motorway that caused no significant damage, and a further second impact that caused severe damage on the west side of the motorway where the aircraft came to rest. Fortunately a small fire in the port engine was quickly extinguished by the waiting emergency services.

A baby, 117 passengers and 8 crew-members were on board the aircraft when it crashed. Thirty nine passengers died at the scene of the accident and the 87 initial survivors were transferred to one of four hospitals in the region (8), - University Hospital, Nottingham; Leicester Royal Infirmary; Derbyshire Royal Infirmary; and Mansfield and District General Hospital.

Injury scoring (AIS & ISS) has not previously been used to assess trauma as a result of a major civil impact aircrash. This paper reviews the AIS and ISS data of all those on board the aircraft and carries out a correlation with occupant survival and the structural damage to the aircraft.

2. MATERIALS AND METHODS

It is well known that passengers often exchange places or move to different empty seats once they have boarded an aircraft (10) and this was discovered to have occurred on this flight. Using the original 'boarding' seating plan and statements made by the survivors, a definitive seating plan (Figure 1) was constructed. Once the position of each occupant had been determined, it was then possible to relate their injury scores to their location within the aircraft.

At the time of the accident, the aircraft broke into three main sections with two main areas of fuselage destruction, forward and behind the wings (Figures 1 & 2). The centre section (overlying the strong wing torque box) remained relatively intact. The accelerations experienced in this region of the aircraft have been calculated as being of the order of 18G in the Gx plane (horizontal) and 22G in the Gz plane (vertical) (15).

In the forward passenger compartment of the aircraft, overlying the forward luggage hold, the floor collapsed with seats in rows 1 to 9 cruhed concertina fashion into one another. In the region behind the wings, the tail of the aircraft jack-knifed through 90 degrees crushing the roof and disrupting the fuselage and seating in this region. Overhead stowage bins, roof panelling and galley equipment became detached from the aircraft fuselage on impact.

The structural damage to the aircraft's fuselage was assessed and scored according to the amount of damage sustained either to the floor, walls or roof of the fuselage for each side, left and right. Damage was scored at each seat row on a scale of 0 - 5, with 0 the score for a normal structure and 5 indicating that the structure was absent. Thus for any given row a score of 0 indicates that the fuselage remained largely intact and a score of 30 that the fuselage was completely destroyed (figure 2).

Regional AIS were calculated for every person on the aircraft using clinical notes and/or post-mortem findings. The American Association for Automotive Medicine Abbreviated Injury Score (1985 revision) was used(1). In this system the body is divided into six regions - head and neck, face, chest, abdominal and pelvic contents, extremities and pelvic girdle and, general (external). The injuries are scored in each region with an increasing severity from 1 to 5. A score of 1 is considered a minor injury wereas a score of 5 is considered a critical injury, survival uncertain. A score of 6 is possible for any given region but is considered to be non-survivable in AIS 85. Figures 4 - 8 record regional maximum AIS for each seat position.

The ISS has been calcuated using the system of Baker et al (2) as the sum of the squares of the 3 highest regional Abbreviated Injury Scores. Therefore ISS = $AIS_{(1)}^2 + AIS_{(2)}^2 + AIS_{(3)}^2$, where $AIS_{(1)}$, $AIS_{(2)}$ and $AIS_{(3)}$ are the three most severly injured regions. Only the contribution of the most major regional injury is used. The highest ISS attainable is 75 (ie. $5^2 + 5^2 + 5^2$) or if any body region scores an AIS of 6, an ISS of 75 is automatically scored. The ISS is a non-linear discontinuous score, with gaps (ie. unobtainable scores such as 7, 15, 23 etc) becoming more frequent as scores approach the maximum possible value of 75 (7).

3. RESULTS

From the seat plan (Figure 1) it can be seen that the majority of deaths occurred in those regions of the aircraft that sustained major structural damage, but there was additional scattered mortality throughout the aircraft.

Figure 3 illustrates the ISS of each person and their location within the aircraft. The average ISS of all occupants on the aircraft was 28 with a range of 1 to 75. Survivors (those 87 removed from the wreckage alive) had an average ISS of 15 (range 1-50) and non-survivors (n = 39) had an average ISS of 55 (range 21-75). Of the initial 87 survivors 30 (37%) had an ISS of 16 or greater.

A significant increase in the mortality rate at the scene was seen in those regions of the aircraft with a structural damage score of 15 or greater (Chi square = 26 with 1 d.f. p=< 0.0005). The ISS was found to correlate with those regions of the aircraft that sustained the most severe structural damage, such that an increasing ISS was associated with greater degrees of fuselage damage (Spearman rank correlation, rho = 0.569 with 116 d.f. p=< 0.0005).

The maximum regional AIS, for each body region is recorded in figures 4 - 8. Analysis of injuries and mortality will be further considered for those 118 occupants seated in the passenger compartment. The injury scores for the crew and those for the child in the mother's arms have been excluded from the analysis because their seating arrangements differed significantly from those seated in the forward facing passenger seats. Deceased occupants were considered to be those 39 patients who died at the scene of the accident. Of those 19 (49%) non-survivors to sustain a maximum ISS of 75 (fig 3), the ISS indicated was as a result of sustaining an AIS of 6 in the regions of head and neck (n = 10, fig 4), and the chest (n = 9, fig 6). These injuries could be considered to be immediately fatal and reflects the severe destruction that occurred to the aircraft in the region in front of the wings.

The variation in average regional AIS in survivors and non survivors is demonstrated in table 1.

Injuries of the head or neck (as indicated by an AIS of 1 or more) were sustained by 33 (85%) of the non-survivors and 31 (39%) of the survivors. Non-survivors sustained significantly more severe head or neck injuries than the non-survivors (Chi square = 37.5 with 3 d.f. p=< 0.0005).

Chest injuries occurred in 38 (97%) of non-survivors and 32 (41%) of the survivors. A significant difference is again demonstrated in the severity of the chest injuries in the two groups (Chi square = 87.5 with 3 d.f. p=< 0.0005).

Twenty eight (72%) of the 'on scene' deaths demonstrated injuries to the abdomen or pelvic contents. This compares with 29 (37%) of the initial survivors. Again a significant difference is seen between the degree of severity in the two groups (Chi square = 30 with 2 d.f. p=< 0.0005).

Similar findings have been identified for the face, extremity / pelvic girdle and the external regional AIS scores. For the face 17 (44%) non-survivors and 8 (10%) survivors sustained facial injuries but they were of greater severity in the deceased group (Fisher exact a probability test p=0.0016). Extremity or pelvic girdle injuries were recorded in 37 (95%) of deceased occupants and 65 (82%) of the survivors. Limb injuries were more severe in the non-survivor group (Chi square = 16.8 with 2 d.f. p=< 0.0002). External injuries were demonstrated in all but two of the occupants with a significant difference in the severity being recorded between survivors and non-survivors (Chi square = 16.8 with 2 d.f. p=< 0.0002).

The occupants of the five rear-facing seats, (occupied by crew members) will be commented on briefly. The ISS of the occupants of the rear facing seats were 10, 8, 5, 4 and 1, giving an average score of 6. These seats were located in regions of the aircraft that remained intact. Statements made by the crew suggest that their injuries had probably been caused by fixtures breaking free.

4. DISCUSSION

The causes of mortality and mechanical injury in an impact aircraft accident have been identified as: crushing within a collapsing airframe; entrapment within the wreckage; being struck by loose objects; absence or failure of restraint; injuries associated with escape; and explosive decompression (7 & 10).

Our study has identified a high mortality and ISS in those regions of the aircraft that sustained severe structural damage. Survivability and low injury severity scores occurred in those regions that remained largely structurally intact, with intact seating and restraint. Injuries to the head or neck, and chest regions appear to account for all immediately fatal injuries seen in the non-survivors. Head or neck, chest and abdominal regional injuries are also seen to contribute significantly to high ISS's.

It has long been recognised that if the force of an abrupt deceleration following an impact excedes the strength of the retaining devices the passenger will be hurled in the corresponding direction sustaining secondary impacts (5). In this particular accident it seems that fuselage failure with collapse of seating was responsible for the severe crush injuries seen in the non-survivors. Conversely in those areas of the aircraft that retained the integrity of occupant protection devices, the devastating injuries to the heads and chests of occupants were less frequent.

A number of occupants who died at the scene sustained ISSs that may have indicated survival was possible. As indicated above a cause of mortality in impact aircrashs is entrapment within wreckage. It is known that the last occupant of the aircrash was removed some eight hours after the accident and subsequently died from his injuries with an ISS of 27. In addition the prescence of fat emboli of varying amounts in all but six of the non-survivors lungs (4) suggests that some injuries may not have been immediately fatal. Pictures of the scene show the large amount of debris within the fuselage which can only have hindered the rescue services.

Significant differences are seen in the severity of injuries (as recorded by AIS) in those who died at the scene and those who survived to be transferred to hospital. Of interest only two survivors sustained visceral intra-abdominal injuries that required operative intervention but 28 non-survivors had sustained a major visceral intra-abdominal injury. The collapsing of the airframe has thus resulted in significantly greater visceral injuries to the abdomen. The high incidence of hepato-splenic injury seen in fatal aircraft accidents, in association with severe head and chest injuries has been commented on in the past (5).

It can be seen that injury scores vary both in survivors and nonsurvivors as well as within differing regions of the aircraft. Why some individuals sustain severe or fatal regional injuries whereas others do not is of great interet to crash the investigators? It is true to say however that injuries to survivors seated in intact regions of the aircraft were caused as a result of the primary forces, and interactions with the occupant protection systems (seats and restraint system) in addition to secondary impacts (as a result of flailing) with the seats in front. It can be seen that a wide spectrum of ISS occurred in the regions that remained intact. Factors that may have contributed include individual variation (age, sex, height, weight etc.), and the position adopted at the time of impact. Three individuals seated in 12D, 14D and 15D (no row 13 on this plane) all sustained severe head injuries (AIS = 5) apparently as a result of a blow to the back of their heads. It would appear they have been struck by a loose object.

The problem of loose objects is further highlighted by the occupants of rear facing crew seats. The majority of injuries sustained by the cabin-crew in these seats were apparently caused by blows from galley equipment which had broken free, or other debris. The problem of overhead furnishings and galley equipment breaking free from their mountings and causing injury following an aircraft accident has been highlighted by the American National Transportation Safety Board (12).

The two cabin-crew sitting in rear-facing seats at the front of the aircraft each had an ISS which was considerably lower than that of forward facing seat occupants in the same region. Fortunately for these crew members they were seated in a strong region of the aircraft that remained intact. The effects of the impact forces on the occupants around them was devastating. The favourable outcome for these crew members raises again the question of the more widespread use of rear facing seats in commercial aircraft .

Comparison of ISS scores sustained by some of the occupants with their neighbours suggests that passenger protection by other occupants resulted in a higher ISS <u>for the protector</u> than the occupant being protected. For example, a patient seated near the front of the aircraft protected the adjacent passenger by putting an arm across the occupants shoulders. The injury severity score indicated that the injuries sustained <u>by the protector</u> were significantly greater than the occupant being protected. The mother in 3F whilst protecting an infant sustained an ISS of 41 whilst passengers seated around had lower scores, as did the infant. Further examples exist in occupants seated in other regions of the aircraft. Increased injury to the protector may be related to the failure of that occupant to adopt a crash brace position.

Injury scoring has proved a useful tool for assessing impact trauma as a result of road traffic accidents. Injury scoring, using the Abbreviated Injury Scale and the Injury Severity Score, has not previously been used in the assessment of injuries in a civilian impact aircrash. Injury scoring techniques have demonstrated that factors other than the impact forces involved may have been responsible for the injuries seen in the passengers and crew. Such factors as entrapment in the wreckage, failure of restraint, collapse of the airframe and being struck by loose objects have long been recognised as causing death in aircraft accidents.

The automobile industry has demonstrated that effective occupant safety system design with adequate restraint, bolstering of interiors and the maintainance of a livable volume decreases the risks of sustaining injury and improves the chances of survival (13). However aircraft impact accidents involve large forces and severe injuries and mortality is inevitable. However this crash and more recent air accidents have demonstrated that survivability is possible for large numbers of occupants, as long as the seating and restraint mechanisms remain intact.

Future designers of aircraft must not only concentrate on reducing the number of fatal injuries, but also examine the cause of non fatal long term disabling injuries in an effort to reduce their incidence. Only if the victim of an aircrash remains relatively injury free can he escape from an aircraft in the event of a fire.

5. CONCLUSIONS

Variations in injuries in passengers can be quickly identified, using injury scoring techniques.

Injury severity scores correlate with structural damage.

Injury scoring techniques highlight variations in injuries amongst passengers and crew which may highlight:-
- Unexpected causes of injury or,
- Factors that prevent injury.

Injury Scoring can provide additional information for the crash investigator.

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SEATING PLAN

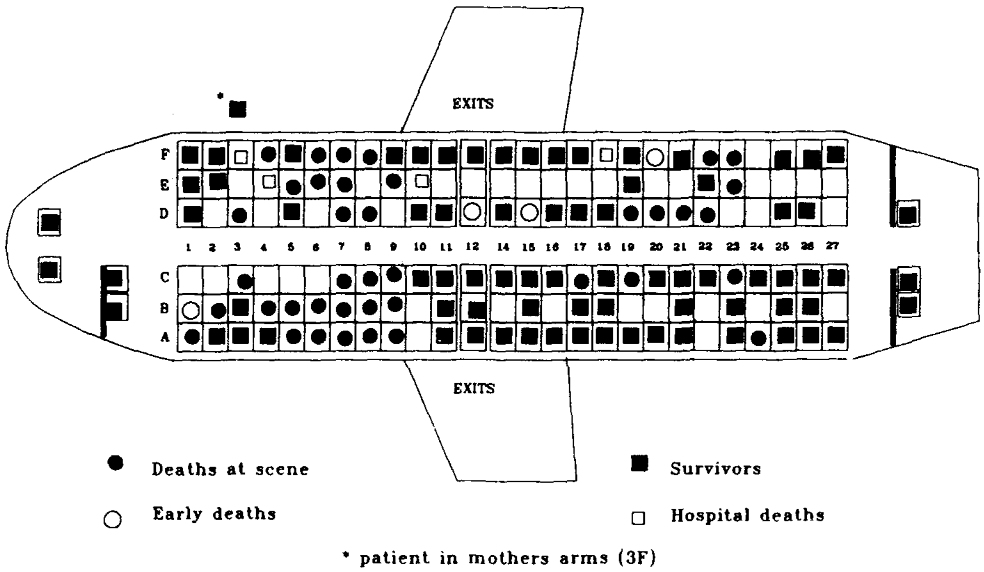

FIGURE 1 area of structural failure

Graphic representation of the airframe structural damage

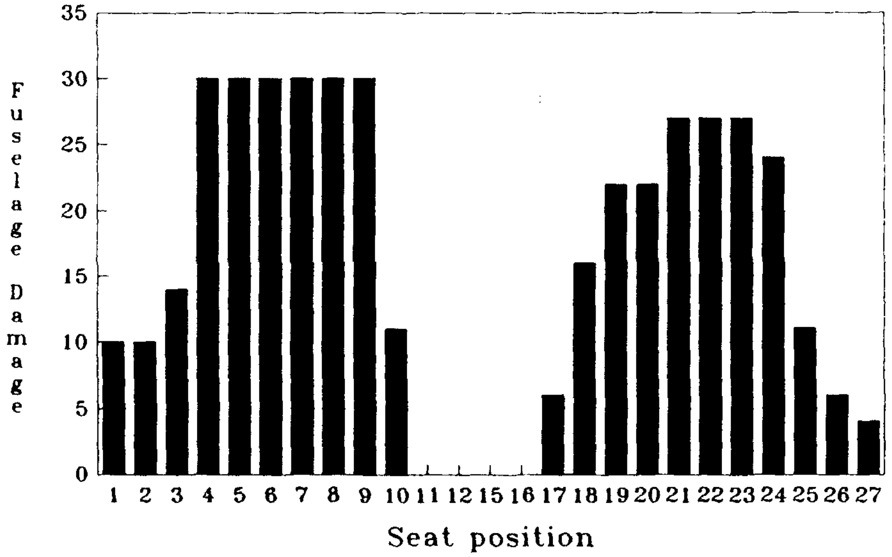

Figure 2

ISS FOR PASSENGERS AND CREW

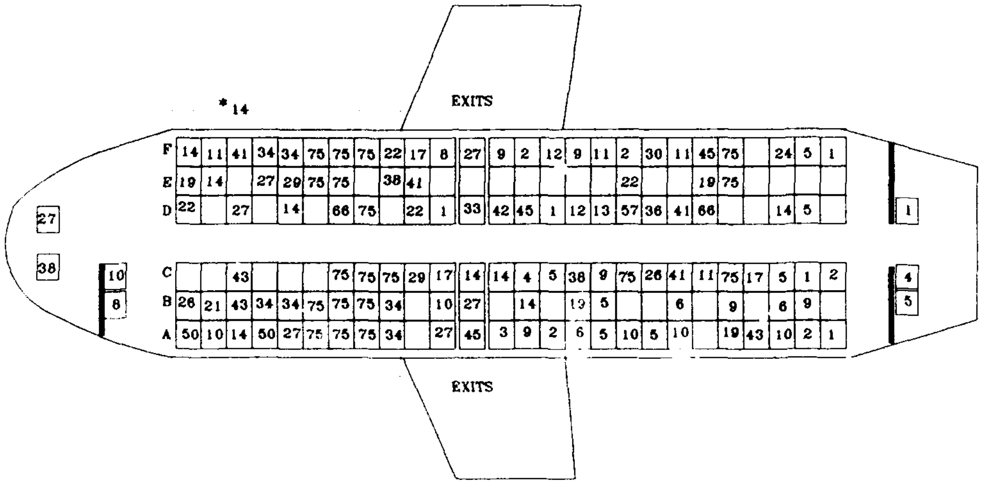

FIGURE 3

Maximum AIS in Occupants - head or neck

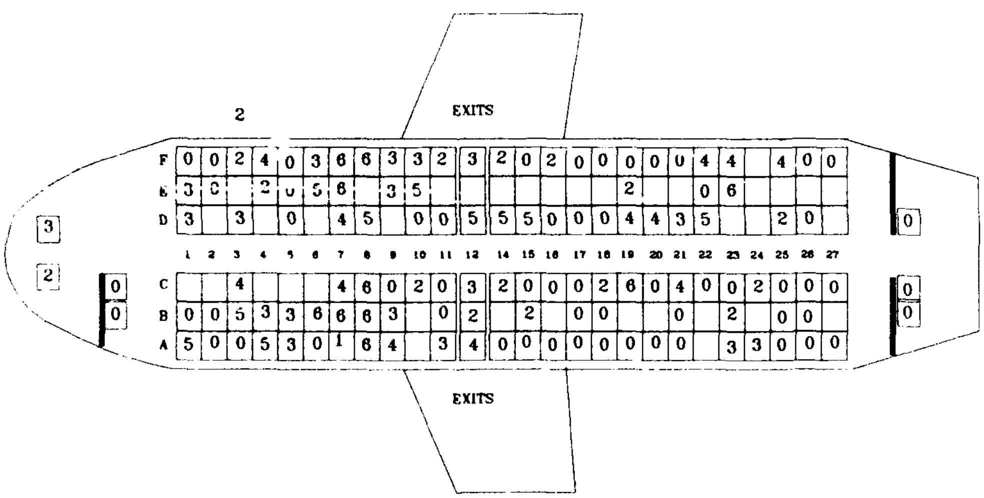

FIGURE 4

Maximum AIS in Occupants – face

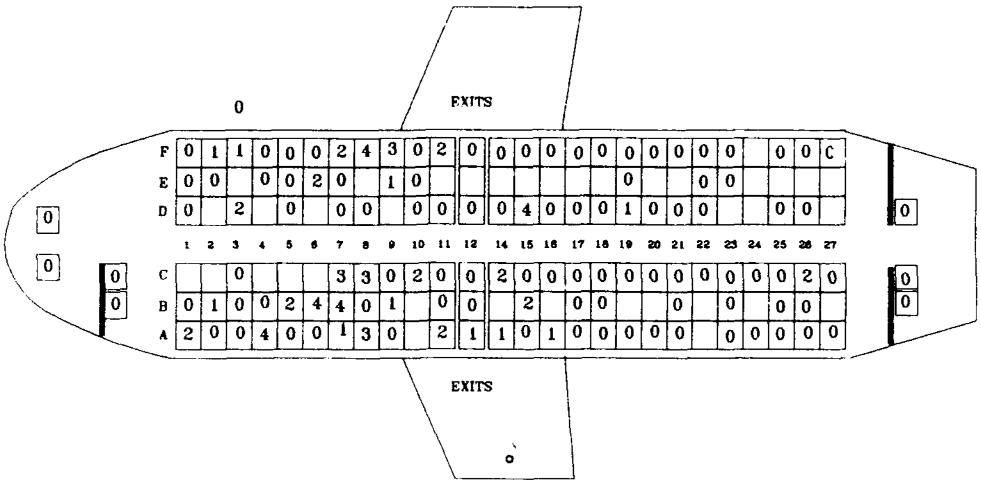

FIGURE 5

Maximum AIS in Occupants – chest

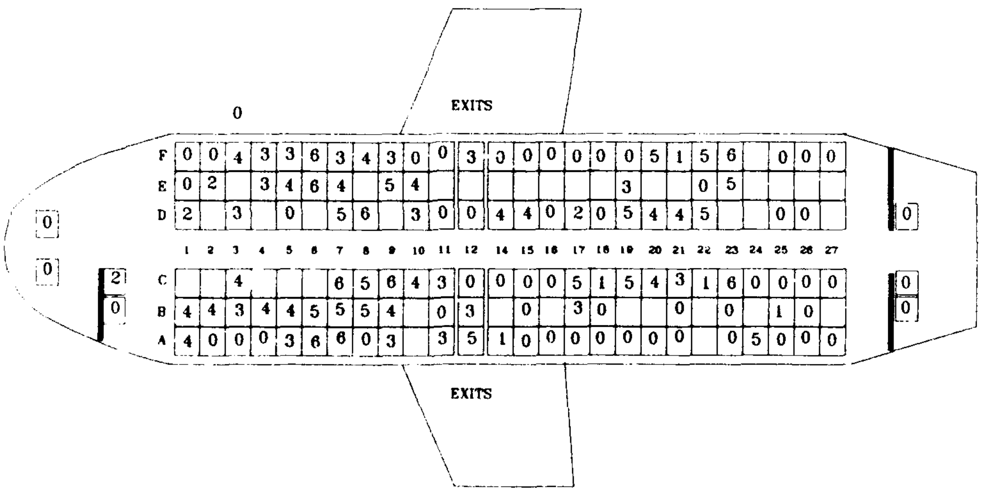

FIGURE 6

Maximum AIS in Occupants – abdomen

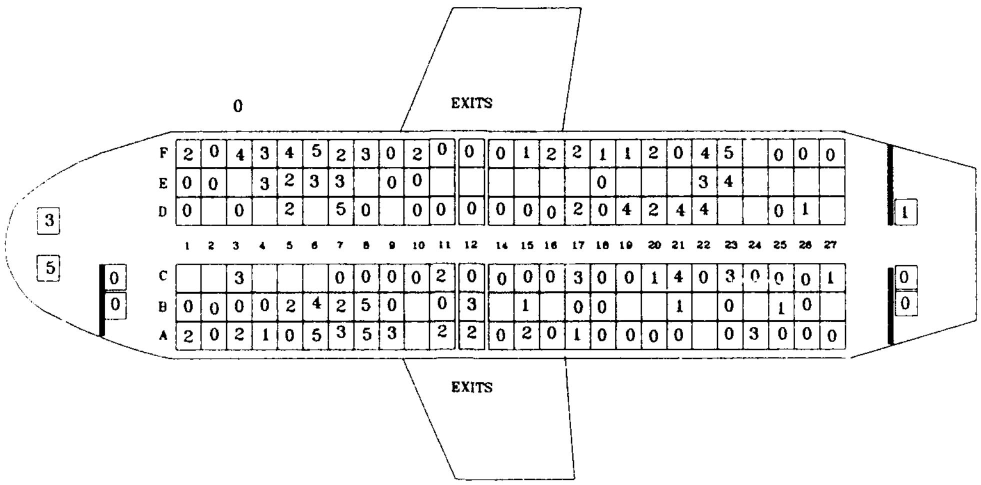

FIGURE 7

Maximum AIS in Occupants – extremities

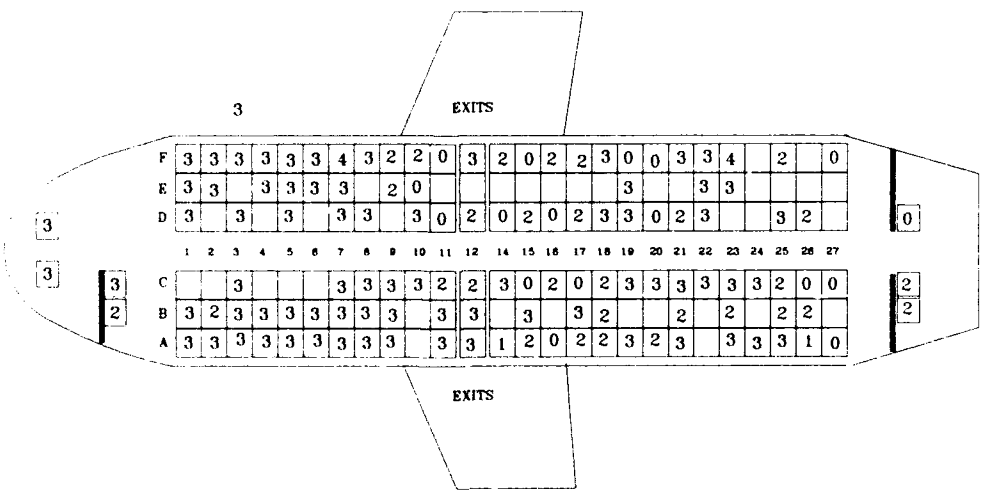

FIGURE 8

Average AIS in Occupants

	Average AIS		*Significance*
	Survivors	Non Survivors	p =<
Head & neck	1.2	3.7	0.0005
Face	0.2	1	0.002
Chest	1.1	4.6	0.0005
Abdomen & pelvic contents	0.7	2.5	0.0005
Limbs & pelvic girdle	2.1	2.8	0.0002
External	1.2	1.7	0.0002

TABLE 1

IS AXIAL LOADING A PRIMARY MECHANISM OF INJURY TO THE LOWER LIMB IN AN IMPACT AIRCRAFT ACCIDENT ?

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SUMMARY:

Following the crash of a Boeing 737-400 aircraft on the M1 motorway near Kegworth, England, on 8 January 1989, it became apparent that a large number of pelvic and lower limb injuries had been sustained by the survivors.

Had there been a fire this would have severely hindered the ability of the occupants to escape.

The mechanism of pelvic and lower limb injuries in impact accidents has been related to flailing of the limbs and axial loading of the femur. The validity of axial loading of the femur as a primary mechanism of femoral fracture in an impact aircraft accident is questioned.

Two methods of study have been used to investigate the impact biomechanics of the pelvis and lower limb: clinical review and impact testing using anthropomorphic dummies.

Our study suggests that in the presence of intact occupant protection systems, bending of the femur over the front spar of passenger seats is the primary mechanism of causation of femoral fractures.

Occupant protection systems designed for civil aircraft should be modified to accommodate loading of the femur over the front of the seat.

1. INTRODUCTION:

On 8 January 1989, a Boeing 737-400 aircraft (G-OBME) crashed on the M1 motorway, near Kegworth, England. The crash sequence consisted of two impacts. On final approach with reduced engine power, the aircraft, in a pitch up attitude, struck the top of the eastern motorway embankment after which the aircraft, rotating to a pitch down trajectory, made its final impact at the base of the western embankment. This impact generated high horizontal and vertical loads resulting in severe fuselage damage.

Following the accident it became clear that a large number of injuries were sustained by the passengers and crew.

In particular, injuries to the pelvis and lower limbs were prevalent (Fig.1). If there had been a fire, these injuries would have severely hindered the ability of the occupants to escape.

Mechanisms of pelvic and lower limb injuries in impact accidents have been related to axial loading of the femur and flailing of the lower limbs. The following scenario has found wide acceptance in impact accidents. On impact a passenger is propelled forwards and the knees strike the bottom of the seat ahead, causing injuries to the knee, upper tibia and lower femur. The impact forces are then transmitted up the femur driving it backwards into the pelvis. This leads to femoral shaft fractures, hip dislocations, acetabular fractures and pelvic shear fractures. This mechanism is a well described scenario in the automobile industry.

This study questions the validity of the above mechanism in the seated occupants of an impact aircraft accident.

2. METHOD:

Two methods have been used to investigate the impact biomechanics of the lower limb and pelvis:
i) Clinical review of the injuries to the passengers in the M1 aircraft accident
ii) Impact testing
These two methods will be discussed.

2.1 Clinical Review:

The case records, radiographs and post-mortem reports of all the passengers and crew were reviewed.

Survivors were interviewed during their hospital stay and subsequently up to one year later. Initial interviews at 3 days recorded the incidence and location of soft tissue injuries and during follow-up visits simple anthropometric measurements were taken with particular reference to the buttock-knee length.

The influence of the crash brace position was analyzed using information from survivors statements, for those seated in the centre section of the aircraft (rows 10-17 and up to row 20 on the port side), where the seating remained attached to the fuselage. Passengers were asked to recall the position that they adopted at the time of impact, in particular the placement of the lower limbs. If the passengers assumed a position as recommended by the British Midland Safety Instruction Card (Fig.2) they were classified as adopting a braced position. Those passengers failing to adopt such a position but bracing in some other manner were described as partially braced. Those passengers remaining seated upright were described as unbraced.

2.2 Impact Testing:

Impact testing was performed at the R.A.F. Institute of Aviation Medicine, Farnborough. The impact facility comprised a wheeled vehicle running on a track 46m long. The vehicle is initially accelerated by stretched bungee cords attached to a bogey. The vehicle coasts immediately prior to the impact.

A multiple row test fixture was selected using seats from G-OBME mounted at a 32 inch seat pitch (Fig.3). Plasticine to a depth of 0.8cm was placed on the posterior spar and the back of the knee panel of the seat in front. Seats were orientated in a Gx plane to simulate -Gx horizontal impacts. An instrumented, Hybrid III, 50%, anthropomorphic test device (A.T.D.) was used as the experimental model. It was placed in the rear of the two row configuration and in the outside seat to enable data collection. A 50% OGLE dummy was placed in the outside seat of the forward row of seats in front of the Hybrid III A.T.D.

The vehicle was fitted with an accelerometer to record the input acceleration of the test fixture. Further accelerometers were placed in the pelvis of the Hybrid III A.T.D. to measure -Gx and +Gz accelerations. Lap belt loads were measured with a pre-calibrated force link attached in series to the lap belt. Knee shear data was recorded for both knees. Pelvis, thigh and ankle displacement data was recorded using the Selspot Motion Analysis System. All impacts were recorded on a high speed video camera system.

The effects of the brace position, lower limb placement and lap belt tension were investigated at vehicle -Gx accelerations of 9,16 and 20G. For each of the designated G levels eight experimental conditions were tested. These eight conditions were randomised within each G level. Each experimental condition was repeated five times and further randomised within each G level. In the braced position the dummy was bent forward until the head was in contact with the seat in front. In the unbraced position the A.T.D. was sat upright in the seat. Two lower limb positions were identified: i) feet forward at an angle of 20 degrees to the vertical and ii) feet back at an angle of 12 degrees to the vertical. The dummy's knees were separated by 4 inches. The dummy was restrained using one of two lap belt tensions, 20 pounds and 40 pounds. The tension was set using a spring balance.

3. RESULTS:

3.1 Clinical Review:

Lower Limb Fractures:
237 pelvic and lower limb injuries were sustained by the occupants of G-OBME, with 142 of these injuries occurring in the survivors (Fig.4).

There were 35 femoral fractures in 31 people (19 survivors and 12 victims) distributed throughout the aircraft.

In areas of extensive structural damage (fore and aft sections) passengers suffered compound comminuted types of fracture as a result of disintegration of the air frame, secondary impacts and crushing (Fig.5). The incidence of fractures in the non-survivors was reported to be lower than for the survivors. This may be true but more likely represents some under-reporting at post-mortem and underlines the desirability of radiographic examination of all crash victims.

In the central section of the aircraft, structural damage was limited and the seating remained largely intact. For occupants seated in this section, a good data set was available with x-ray documentation of their injuries. Therefore, for the purposes of this review, attention has been directed at this group of passengers.

Fracture Types:
There were 10 femoral fractures in 9 passengers seated in this section of the aircraft. Many were proximal femoral fractures. Fracture types included, transverse, transverse with butterfly fragment, oblique and spiral fractures suggesting that one simple mechanism of injury could not fully explain all fractures.

Soft Tissue Injury and Fractures:
If axial loading of the femur was a primary fracture mechanism then one would expect evidence of soft tissue injuries around the knee, indicating impact. Fig.6 shows that in the central section of the aircraft, 16 of the 38 occupants sustained soft tissue injuries around the knee. In those 16 passengers only 4 sustained a femoral fracture. This compares with 7 femoral fractures in the remaining 22 passengers with no evidence of soft tissue injury. Thus there appears to be no relationship between soft tissue witness marks around the knee and femoral fracture.

Anthropometric Measurements and Injury:
Similarly with axial loading it would be expected that patients with a greater than average buttock-knee length would show an increased incidence of soft tissue injury around the knee. This was not the case (Fig.7).
However, an increased buttock-knee length was associated with an increase in the rate of femoral fracture (Fisher Exact Test p= 0.344).

Bracing and Fractures:
Six of the nine femoral fractures occurred in individuals who adopted a braced position, with one occurring in a partially braced occupant and two in patients who were unable to recollect the position that they adopted at the time of impact. This apparent increase in the incidence of femoral fractures associated with the braced position is not statistically significant (Fisher exact probability test p=0.6849).

Seat Damage and Femoral Fracture:
There was an association between the incidence of femoral fractures and seat position. Of those 6 passengers sitting in a central seat row, 4 sustained femoral fractures. This compares with five femoral fractures in the remaining 32 patients not seated in a central seat. This difference is statistically significant (Fisher exact test p=0.0398).

3.2 Impact Testing:

Motion of the Dummy:
Review of the high speed video recordings made it apparent that on no occasions, at a 32" seat pitch, did knee contact occur with the back of the forward seat (as evidenced by the lack of indentation in the plasticine). This suggests that significant axial loading of the femur does not occur as a result of knee impact with the seat in front, in this test configuration.

Flailing of the lower limbs under the seat in front was shown not to apply in all situations. Positioning the lower leg such that it lies 12 degrees behind a line drawn vertically through the knee prevented flailing of the lower leg in all the experimental conditions.

Horizontal knee displacement increases with increasing -Gx acceleration and with decreasing lap belt tension. A maximum knee displacement of 19(cm) occurred at 20G, indicating that on impact the femur translates forwards such that the proximal femur comes to lie over the front spar of the seat.

Vertical knee displacement was greater when the legs flailed (maximum =126mm +/- 4mm) than when they did not (45mm +/- 26mm). High speed video showed that with increasing knee displacement the thigh impinges over the front seat spar to a greater degree. This suggests that the femur may be loaded over the front spar especially when leg flail occurs.

4. DISCUSSION:

The accepted mechanism of injury to the femur is described below. On impact a passenger seated in an intact region of the aircraft is propelled forwards. The knees strike the bottom of the seat in front causing injuries to the knee, upper tibia and lower femur. The impact forces are then transmitted up the femur driving it backwards into the pelvis. This is said to lead to femoral shaft fractures, hip dislocations, acetabular fractures and pelvic shear fractures.

Evidence provided from the clinical review of passengers seated in the middle section of this aircraft and from impact testing suggests that this may not be the case as:

1) Differing fracture types were found including, transverse, transverse with butterfly fragment, oblique and spiral fractures. This suggests that no one simple mechanism of injury explains all fractures.
Transverse fractures are produced by bending or flexural load. The butterfly fragment transverse fracture is a variation on this theme with the added element of compression in conjunction with bending. Oblique fractures are produced by a combination of torque and compression. Spiral fractures indicate a torque mechanism. Comminuted fractures with multiple bone fragments are usually seen as a result of high energy transfer with the load concentrated over a small area.

2) Soft tissue injury around the knee was not associated with femoral fracture or an increased buttock-knee length.

3) Impact testing has demonstrated that knee impact did not occur with the back of the seat in front in any of the experimental conditions.

From the clinical review the following facts emerge:

1) The typical femoral fracture was proximal.

2) There was a significant increase in the incidence of femoral fracture in the central seats of a row. In these seats the front spar is supported more rigidly.

3) In the outside seats the front spars demonstrated bending.

4) There was an increase in the incidence of femoral fractures in people who adopted a braced position and in those with longer than average femurs although these differences were not statistically significant.

From impact testing the following facts emerge:

1) The lower limb and pelvis appears to be loaded at 3 fixed points;
  a) the lap strap
  b) the front spar of the seat
  c) the posterior spar of the seat in front.

2) On impact the body is translated forwards such that the proximal femur comes to lie over the front spar of the seat.

3) Hyperextension of the knee occurs when the lower legs flail and vertical knee displacement is greatest in this situation.

These facts suggest that a bending mechanism may be important in the production of femoral fractures.

It appears that on impact the slack in the lap belt is taken up and the pelvis is loaded. The femur translates forwards so that its proximal portion comes to lie over the front spar of the seat. The distal femur is loaded as it passes under the posterior spar of the seat in front and the loading is increased by flailing of the lower legs (Fig.8).

This proposed mechanism would explain why femoral fractures were predominantly proximal and why transverse fracture patterns were seen. Moreover, bending failure of the front spar would introduce an element of rotation or torque into the fracture mechanism thereby accounting for some of the other fracture types seen.

The increased incidence of femoral fractures in those individuals seated in a central seat can be attributed to the increased rigidity of the front spar in this location.

There was an increased incidence of femoral fracture in those who adopted a braced position. It is interesting that at impact testing, vertical knee displacement was seen to be greatest in the braced, legs forward, position perhaps indicating greater loading of the thigh.

Furthermore, clinical review suggests that those individuals with longer than average femurs sustained more femoral fractures. If a bending mechanism is relevant then with a longer lever an increased bending moment will be experienced and hence fractures would be more likely.

These experiments suggest that axial loading is not the primary mechanism causing femoral fractures in the seated occupants of an impact air crash.

Instead a bending mechanism appears to be involved where the proximal femur is loaded over the front spar of the seat.

This research raises several important questions:
1. Does a bending mechanism explain the pattern of femoral fractures seen in the seated occupants of an aircraft crash?

2. What effects do changes in body posture have on the loads produced in the lower limbs. In particular, bracing with the feet forward leads to an apparent increase in femoral fractures. Is this a result of flailing.

If flailing does not occur with different placement of the lower limbs then how will this effect the loads acting on the femur and what are the consequences in terms of possible other injury patterns for the lower limb.

3. What is the optimum brace position for an aircraft crash?

FIGURE 1:

Major Injuries in Survivors of the M1 Aircrash

(For 87 Patients Surviving the Crash)

INJURY	No
HEAD	43
THORACIC	23
ABDOMINAL	2
SPINAL	24
PELVIC/LOWER LIMB	142
UPPER LIMB	59

FIGURE 2: Brace Position
From British Midland Safety Instruction Card 1989

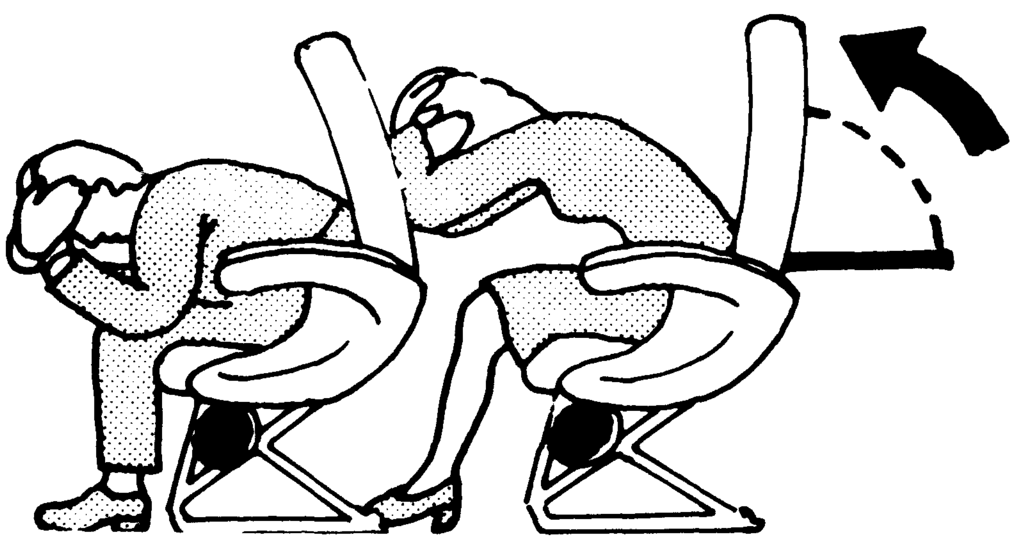
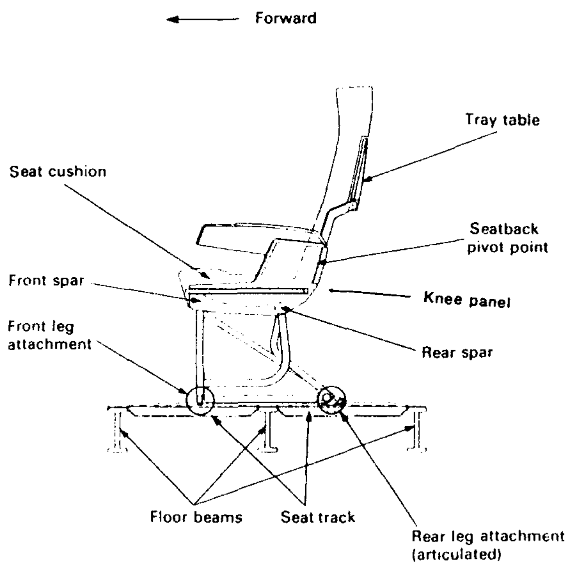


FIGURE 3: Passenger Triple Seat



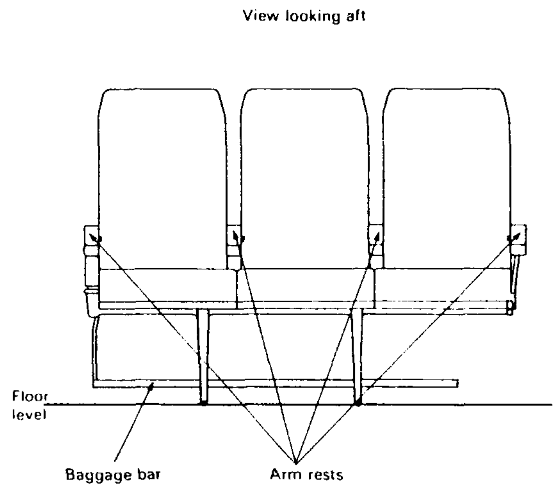


FIGURE 4:

M1 Aircrash :
Lower Limb Injuries
(Total of 237 Injuries in all Occupants)

REGION	NUMBER(%)	PEOPLE(%)	%COMPOUND
PELVIS	32 (13%)	32 (25%)	0%
FEMUR	35 (15%)	31 (25%)	3%
KNEE	23 (10%)	22 (17%)	35%
TIBIA	69 (29%)	54 (43%)	64%
ANKLE	50 (21%)	42 (33%)	54%
FOOT	28 (12%)	23 (18%)	46%

FIGURE 5: Distribution Of Femoral Fractures

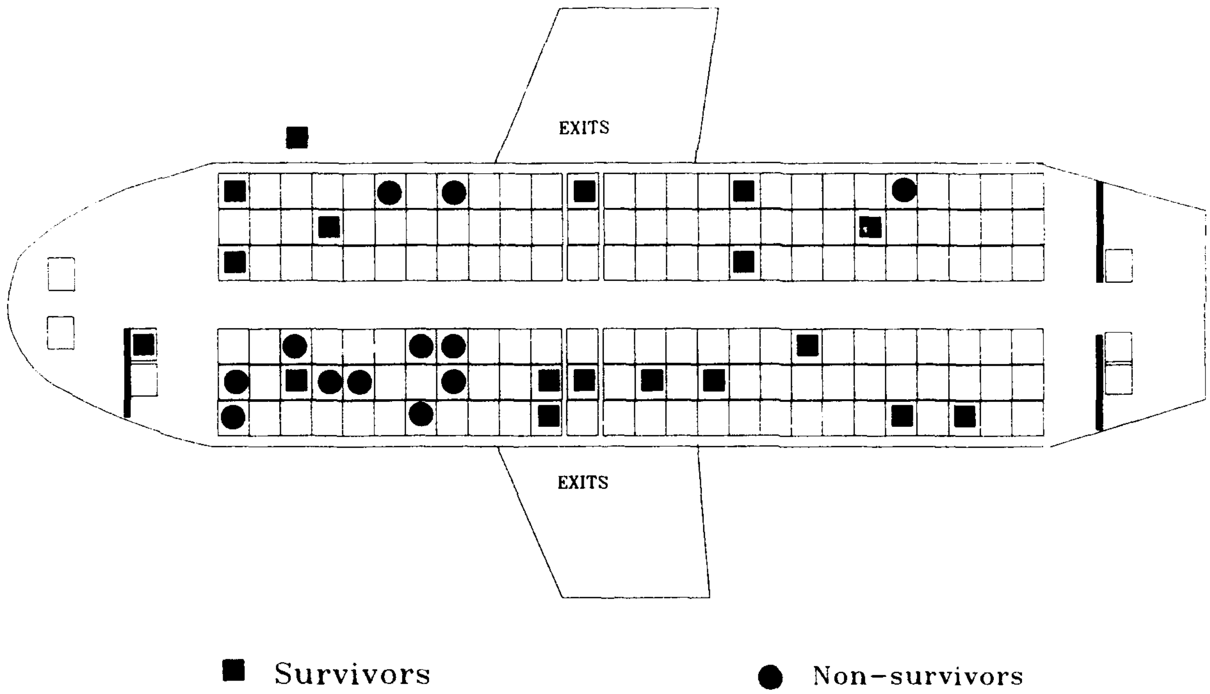


FIGURE 6:

Soft Tissue Witness and the Presence of a Fracture Associated with Axial Loading

		YES	NO
FEMORAL SHAFT FRACTURE	YES	4	7
	NO	12	15

Fisher p=0.6849

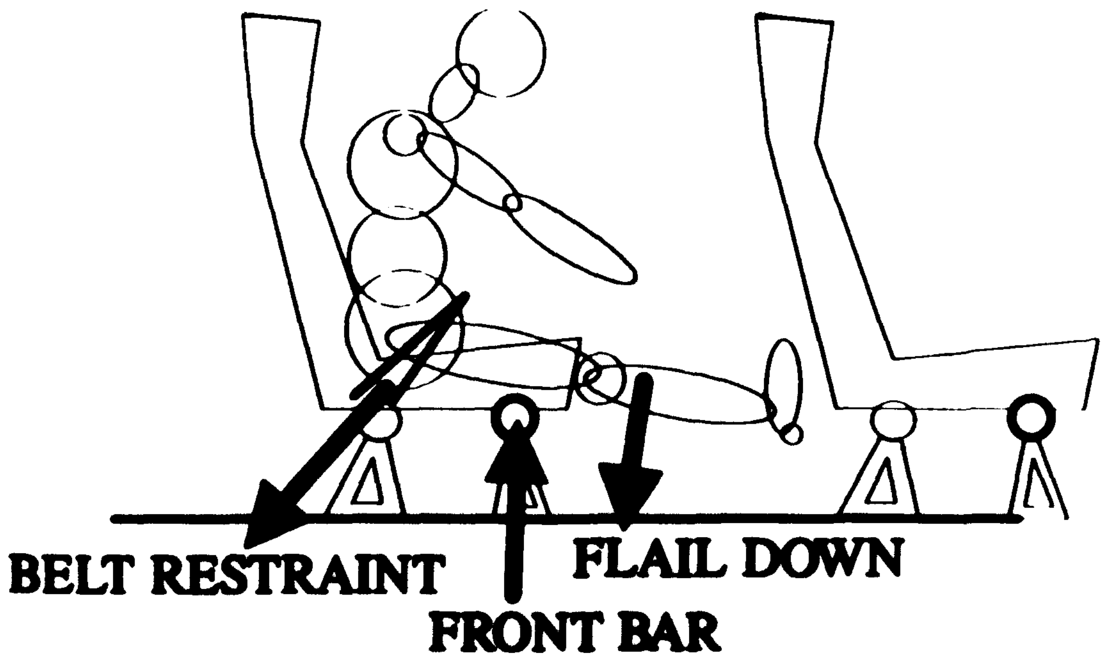
FIGURE 7:

Buttock - Knee Length and Soft Tissue Injuries Around the Knee

		GREATER THAN MEAN	LESS THAN MEAN	UNKNOWN
SOFT TISSUE INJURY AROUND KNEE	YES	4	9	3
	NO	8	8	6

Chi-square p=0.505

FIGURE 8:



Occupant Simulation as an Aspect of Flight Safety Research

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ABSTRACT

In the field of flight safety research there is a growing interest for mathematical simulation of human response and injuries associated with survivable aircraft accidents. A mathematical tool can be very helpfui to evaluate and improve on-board restraint systems or to assess the effectiveness of different seat designs. The passenger brace position, being a human factor, can be evaluated efficiently as well.

MADYMO is a well accepted integrated multibody/finite element program for Crash Victim Simulation. Recently the two-dimensional version of MADYMO was successfully applied for reconstruction of seat and passenger behaviour during the M1 Kegworth air accident. In this paper a brief description of MADYMO as well as three flight safety applications are presented. Special attention is given to the application concerning a dynamic seat test involving a 50th percentile Hybrid II dummy and a P3/4 dummy, representing a nine-month-old child, seated in a child seat. The MADYMO model used for this application was validated on the basis of sled test results. It can be learned that MADYMO is capable of predicting passenger and seat response in an aircraft crash environment. A discussion on future developments in this field concludes this paper.

INTRODUCTION

In safety research the simulation of crashes is of vital importance in order to evaluate and improve safety devices and human body surroundings. Most of this work is done experimentally with instrumented dummies or human cadavers. Occationally animals or human volunteers are used. During the past years a strong increase could be observed in the use of computer simulations due to both the fast developments in computer hardware and simulation software. Simulation programs can contribute significantly to the insight into impact behaviour of complex dynamical systems, particularly if models are used to complement experimental work.

Examples of computer simulation programs for aircraft crash safety analyses are KRASH, SOMLA/SOMTA (Seat Occupant Model-Light Aircraft/Seat Occupant Model-Transport Aircraft) and ATB (Articulated Total Body). The program KRASH uses masses interconnected by massless beams and springs to model the crash behaviour of aircraft structures, while seats and passengers can be represented by mass-spring systems in order to obtain a rough indication on the injuries sustained [9,13]*. Figure 1 shows a KRASH model of a helicopter. The programs SOMLA and SOMTA combine a three-dimensional multibody model of aircraft occupants with a finite element model of the seat structure [3,14]. SOMLA models a single occupant, whereas SOMTA has the capability to model up to three passengers. Only a fixed number of segments can be specified for representation of the occupant in SOMLA/SOMTA. The ATB program is based on the CAL 3D multibody model for crash victim simulation in the automotive field [1]. Several modifications were introduced, e.g. the capability to apply aerodynamic forces to the human body.

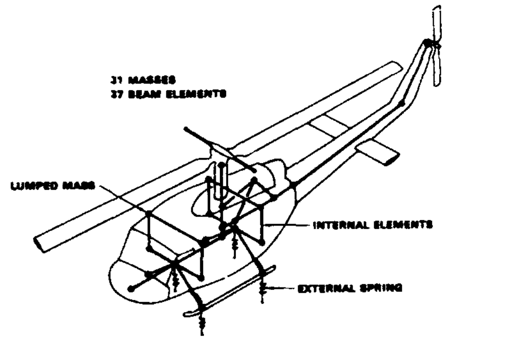

Fig. 1 KRASH model of a helicopter [13].

Due to modification of the Federal Aviation Regulations (FARs) in view of an increased on-board passive safety level and the growing awareness that a notable high percentage of aircraft crashes are survivable nowadays, the aeronautics industry starts to use advanced simulation tools which are customary in the automotive industry. Among these tools are several explicit finite element codes, especially useful to determine the crash behaviour of aircraft structures, and the integrated multibody/finite element program for crash analyses MADYMO. The main emphasis of this program is the prediction of the kinematics and dynamic behaviour of crash victims. Recently the two-dimensional version of this program was successfully applied for reconstruction of seat and passenger behaviour during the M1 Kegworth air accident [10,11].

* Numbers in parentheses designate references at the end of paper.

In this paper first a brief description of MADYMO is given as well as an overview of available crash dummy databases. Than some earlier MADYMO flight safety applications will be discussed, namely the in-flight escape of a crew member from the Space Shuttle and a three-dimensional simulation of seat and passenger behaviour during the M1 Kegworth air accident. A third more recent example to be presented concerns the simulation of a dynamic seat test involving a 50^{th} percentile Hybrid II dummy and a P3/4 dummy, representing a nine-month-old child, seated in a child restraint system. Simulation results obtained from this example will be compared with the actual sled test results. Different concepts for modelling the seat structure will be addressed. A discussion on the possible contribution of computer simulations to the overall flight safety problem and future MADYMO developments concludes this paper.

MADYMO

MADYMO is a world-wide accepted engineering analysis program, developed by the TNO Crash-Safety Research Centre, for the simulation of systems undergoing large displacements. The program has been designed especially for the study of the complex dynamical response of the human body and its environment under extreme loading conditions like they occur in crash situations. But also for other dynamic events, like the simulation of vehicle riding and handling the program has been applied succesfully. MADYMO combines in one simulation program, in an optimal way, the capabilities offered by the multibody approach (for the simulation of the gross motion of systems of bodies connected by complicated kinematical joints) and the finite element method (for the simulation of structural behaviour).

The multibody part of the program uses a relative description for the kinematics of systems of bodies. The generation of the equations of motion is based on the principle of virtual work in combination with a recursive algorithm for the motion of the bodies. This formulation offers a very versatile and economical way for the description of the motions in arbitrary kinematical joints. Figure 2 illustrates a number of standard joints available in MADYMO (version 5.0). In addition to these joints a user can define new joint types by means of user defined routines.

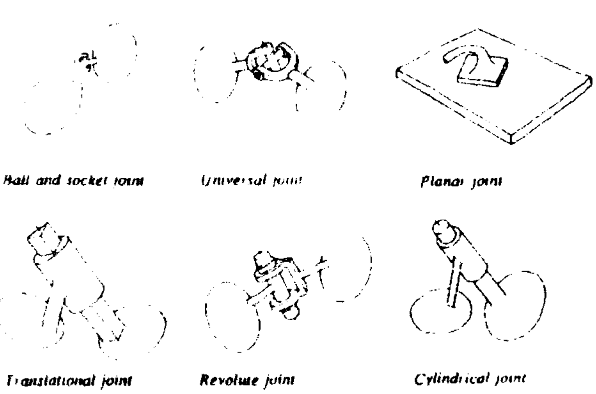

Fig. 2 Standard 3D kinematic joints in MADYMO.

To the bodies ellipsoids or planes can be connected for contact interaction with other bodies and the environment. Moreover a library of force models is available including, for instance, belt models, airbags and several types of spring and damper elements [4].

For the simulation of structural deformations the multibody elements can interact with structures modelled with finite elements. Triangular membrane elements of constant thickness with special material models for fabrics have been implemented for the simulation of airbag dynamics (see Figure 3) [8,15,16,18]. In addition interfaces are available between MADYMO and the explicit FEM codes PAM-CRASH, LS-DYNA3D and DYTRAN for integrated human body-vehicle structural crash analysis [7].

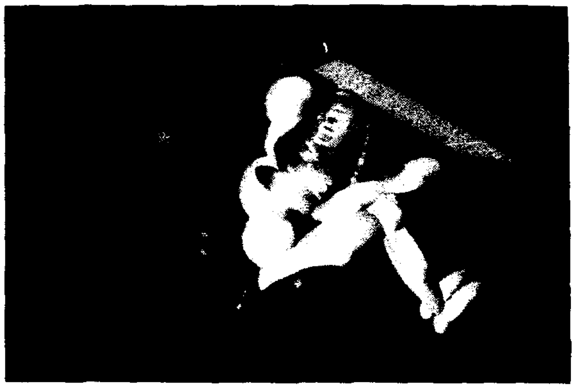

Fig. 3 Example of coupled MADYMO multibody/FEM simulation.

MADYMO as an injury biomechanics program offers, in addition to standard output quantities like displacements and accelerations, which can be visualized through advanced animation and time-history programs, the possibility to calculate injury criteria like femur and tibia loads, internal joint loads, HIC, SI, TTI, and V*C.

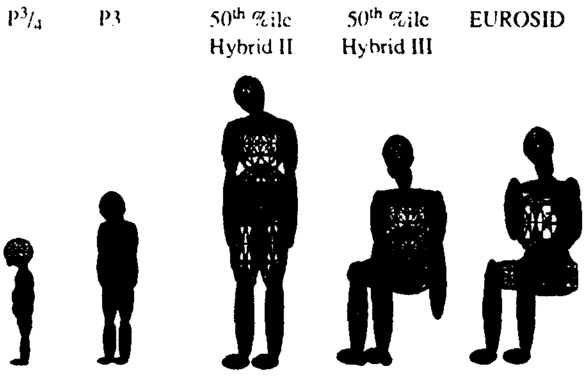

Fig. 4 Some of the standard crash dummy databases available in MADYMO.

An important requirement for an effective use of computer models in the field of crash simulations is that reliable well validated descriptions for the human body are available. MADYMO offers a number of standard databases for crash dummies [5]. Some of them are illustrated in Figure 4, i.e.

models for the nine-month (P3/4) and three-year-old (P3) TNO child dummies, the 50th percentile adult frontal impact dummies Hybrid II and Hybrid III and the European side impact dummy EUROSID. Databases for the USA side impact dummy SID, and the 5th- and 95th percentile Hybrid III dummies are available as well. In addition to crash dummy databases also capabilities are offered in MADYMO to generate real human body antropometry and mass distribution data.

EARLIER MADYMO FLIGHT SAFETY APPLICATIONS

Among the MADYMO applications and validation studies published in the past [12] are simulations of occupants in frontal and side impacts, pedestrians and cyclists hit by a passenger car front, wheelchair occupants during transport, a child in a child restraint system, simulation of human body segments in a crash environment and evaluation of sports protection devices. In addition, several studies were carried out on truck driver safety, pedestrians and cyclists contacting a truck front or various side structures of the trailer and motorcycle simulations.

In this paper first two earlier flight safety applications will be briefly discussed; an in-flight escape of a crew member from the Space Shuttle and the three-dimensional seat and passenger behaviour during the M1 Kegworth air accident.

Space Shuttle escape

The simulation concerns the in-flight escape of a Space Shuttle crew member [2]. One of the potential methods evaluated by NASA to obtain a safe escape from the Space Shuttle made use of a tractor rocket escape system. The astronaut is laying backwards on a horizontal ramp with his feet placed on a vertical foot plate. A small hatch at the side of the Space Shuttle is available for the escape. The crew member harnass system is connected to the tractor rocket by means of an elastic rope, further referred to as pendant line. After ejection of the tractor rocket the pendant line will become stretched and the astronaut is pulled through the hatch opening.

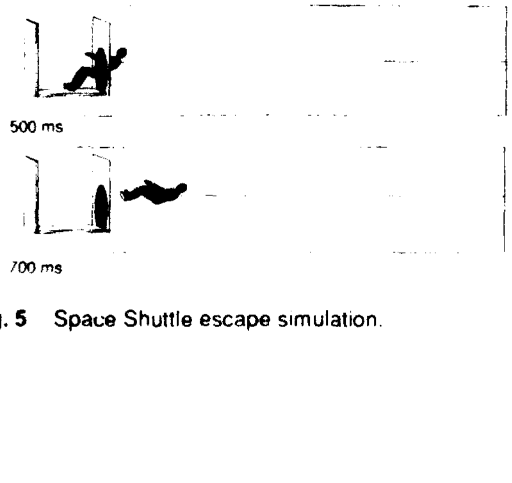

Fig. 5 Space Shuttle escape simulation.

Anthropometry, mass distribution and joint properties of the astronaut model are based on a 50th percentile Hybrid II dummy. Aerodynamical forces on the astronaut are described as an acceleration field. The propulsion force on the rocket is estimated. The pendant line is simulated by a spring-damper element, both elastic and damping properties are estimated as well. The Space Shuttle itself is represented by a number of contact planes to study the interaction with the astronaut. Figure 5 presents the simulated astronaut and rocket locations during the first 700 ms. By means of the developed model, the influence of different parameters like body size, initial position, pendant line stiffness and pull angle on the astronaut response can be investigated.

Aircraft seat and passenger behaviour during a crash

On the night of Sunday the 8th of January 1989 a Boeing 737-400 crashed on the M1 motorway near Kegworth in England. Of the 126 passengers on board 79 survived the accident. A comprehensive investigation into the cause and effects of this accident was carried out by a study group of representatives of various organisations. Besides structural, medical and survival aspects attention was paid to the reconstruction of the accident by means of computer simulations. The aircraft overall behaviour during the crash was simulated by Cranfield Impact Centre Ltd. with the program KRASH. From this simulation movements in time and deceleration pulses of different aircraft sections were obtained [9]. The movement and deceleration of the mid section were used as input for MADYMO 2D, allowing an analysis of seat and passenger behaviour during the crash. As a result of this analysis, which was performed by HW Structures Ltd., possible injury mechanisms could be identified [10,11]. The influence of different passenger brace positions on the injuries sustained was studied as well.

The three-dimensional simulation presented here is based on the MADYMO 2D simulations; in fact all input data originate from a Civil Aviation Authority report prepared by HW Structures Ltd. [6]. Figure 6 illustrates the simulated passenger kinematics. Two aircraft seats behind each other are occupied by 50th percentile Hybrid III dummies, both dummies are restrained by a regular lap belt. Floor and bulkhead rotation is prescribed in the MADYMO input dataset. A seat is defined as a separate system composed of two elements, for representation of seat cushion and seat back respectively. Both seats are attached to the floor by means of point-restraints, four point-restraints are used for each seat. This model set-up allows for attachment deformation to be taken into account, moreover the seats can easily be moved in the model. Gravity combined with longitudinal, vertical and lateral crash pulse components are applied. As can be learned from Figure 6, quite severe head impact occurs for both passengers when seated in an upright position initially.

DYNAMIC AIRCRAFT SEAT TEST

A dynamic aircraft seat test was performed by TNO. This test was carried out in accordance with FAR regulations (Part 25). To account for the effects of floor deformation that may occur during an accident, this regulation prescribes the track on one side of the seat to be rotated 10° about the lateral (pitch) axis and the other track to be rotated 10° about the longitudinal (roll) axis, as illustrated in Figure 7. For the test the seat legs were fixed to a flat steel plate (via the original floor tracks) instead. Figure 8 shows the initial test set-up. The double-seat is occupied by a 50th percentile Hybrid II dummy and a P3/4

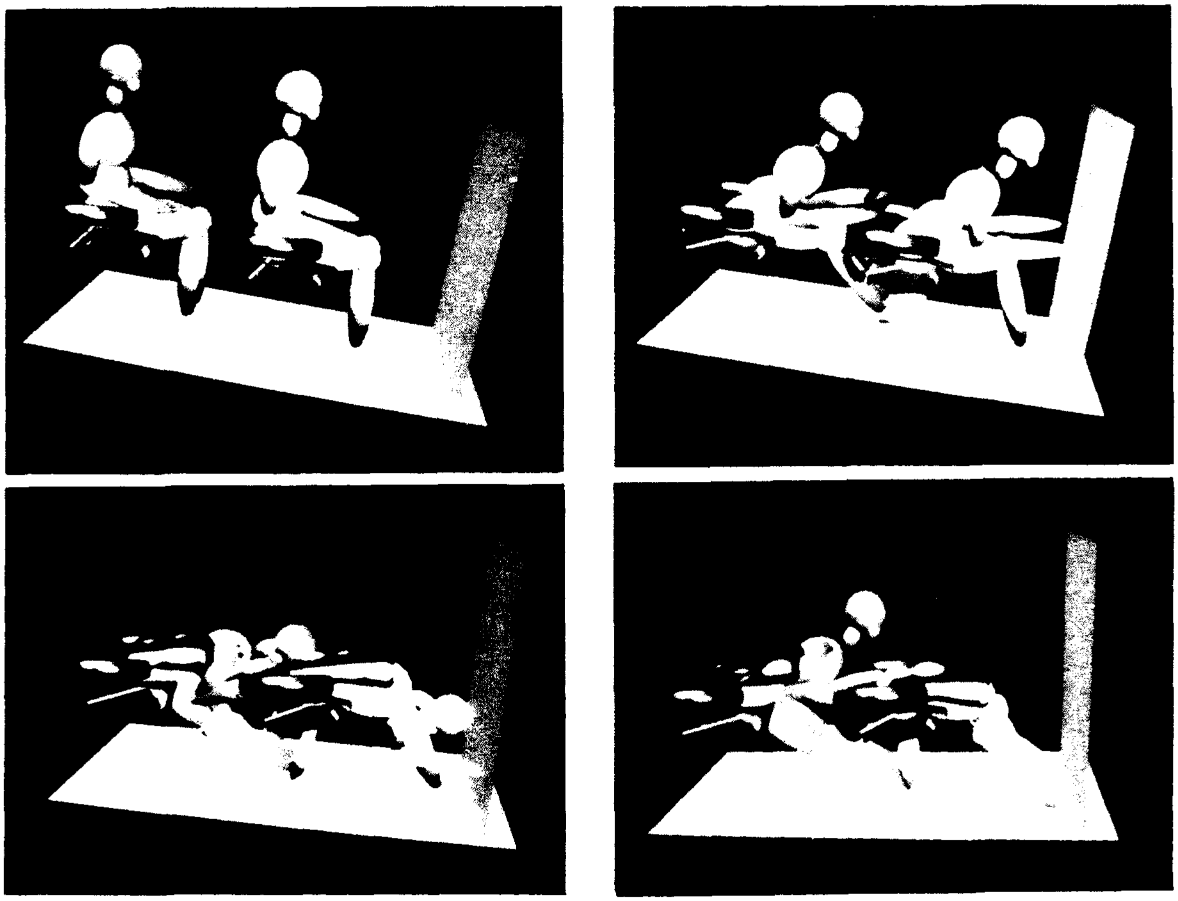

Fig. 6 Simulated seat and passenger behaviour during an aircraft crash.

child dummy in a child seat. Both 50th percentile Hybrid II dummy and child seat are restrained by the standard lap belts during the test. The 50th percentile Hybrid II dummy was not equipped with a lumbar spine load cell as prescribed in the regulations, since no potential for spinal injuries was anticipated. The double-seat was rotated 10° relative to the acceleration direction of the HYGE sled. Figure 9 shows the acceleration pulse of the sled. As can be seen in this figure the acceleration pulse applied differs only slightly from the ideal triangular pulse as included in the FAR dynamic test requirement. No seat structural deformations of importance could be identified after the test (see Figure 10). Note that the cover of the right armrest has been removed in this figure. The sled test, as described above, was simulated utilizing the MADYMO 3D program.

Model set-up
The MADYMO 3D model set-up is given in Figure 11. The double-seat is represented by a system composed of three elements, for modelling seat cushion and both seat backs respectively. Since a similar seat design was tested as the seats on-board of the Boeing 737-400 crashed near Kegworth, most input data was derived from the Civil Aviation Authority report prepared by HW Structures Ltd. [6]. Only a few additional measurements were carried out in order to obtain missing information.

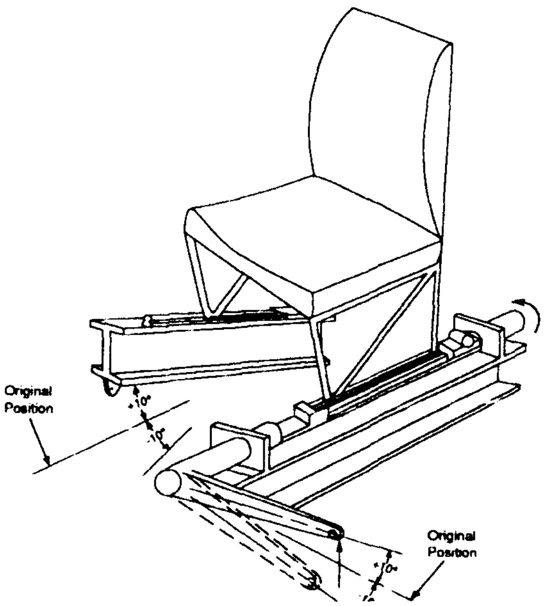

Fig. 7 Floor wraping conditions according to FAR (Part 25, test 2) [14].

Fig. 8 Dynamic seat test set-up.

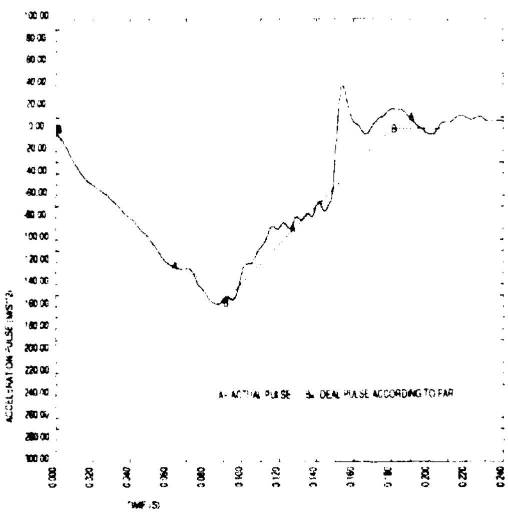

Fig. 9 HYGE sled acceleration pulse.

Fig. 10 Seat structure after the test.

Fig. 11 MADYMO model set-up for dynamic seat test simulation.

Validation study

Figure 12 shows the simulated kinematics of both dummies and the child seat (note that higher order ellipsoids are visualized as 2nd order ellipsoids in this figure). The validation study presented here will focus on the behaviour of the 50th percentile Hybrid II dummy. When comparing the simulated kinematics of this dummy with the kinematics observed during the sled test, it can be learned that the computer model predicts a slightly too fast forward motion of the upper part of the body. In the simulation the Hybrid II dummy does not touch the seat front tube, which could explain why no deformations of the front tube could be identified after the actual test.

The simulated acceleration components of the Hybrid II lower torso and head are compared with the accelerations measured during the experiment in Figure 13, whereas Figure 14 compares the simulated and experimental lap belt forces. These lap belt forces were recorded at the left and right side of the dummy pelvis. In general a fairly good correlation can be observed between simulated and experimental signals. The peak at 140 ms in the lateral and vertical component of the lower torso acceleration signal is probably due to contact with the armrest when the dummy rebounds from the seat. The magnitude of the belt forces is correct, however, the curve shapes could be improved further by taking into account the deformation and rotation of the belt anchor points.

GENERAL DISCUSSION

Since its appearance on the market the MADYMO program has been continuously modified and improved. In its present form the program appears to be a very useful tool to users all over the world for simulation and analysis of human body behaviour during a crash or impact. Although primarily used for automotive safety applications, the aeronautics industry shows an increasing interest as well. A lot can be learned from knowledge and techniques which are common use in the automotive industry, such as energy absorbing interior paddings, seat belts, child restraint systems or airbags. Weight

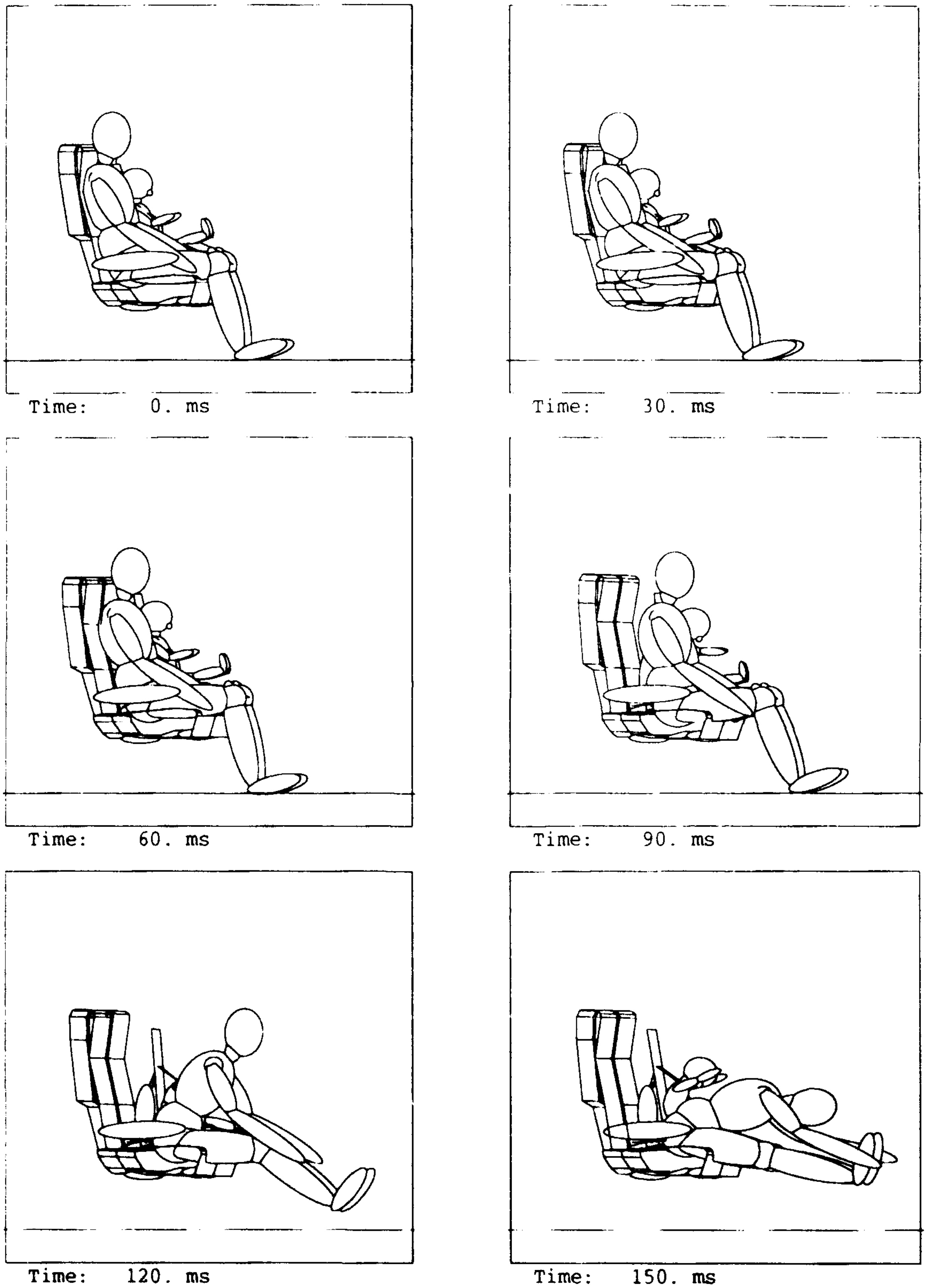

Fig. 12 Simulated kinematics.

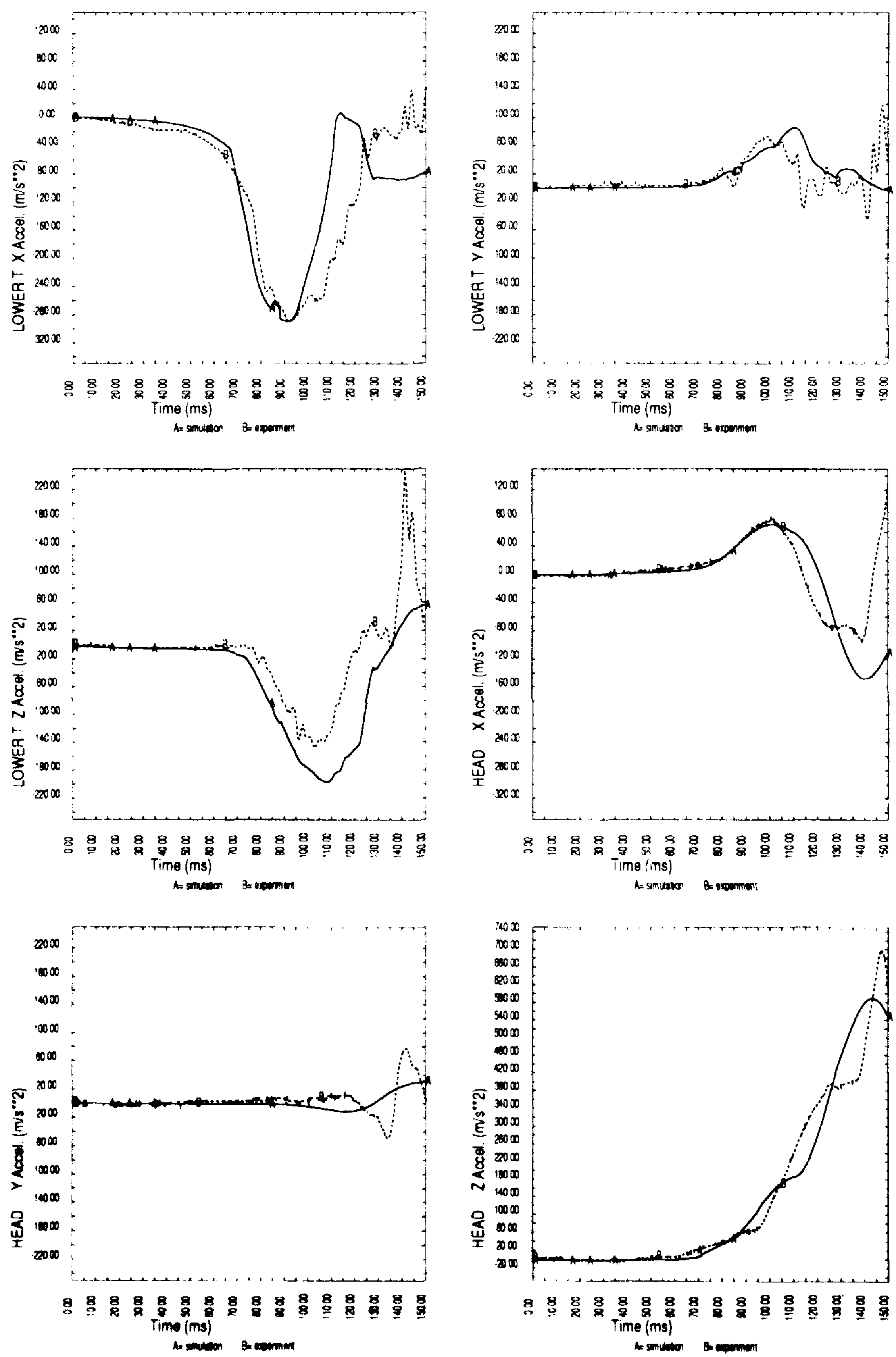

Fig. 13 Comparison between simulated and experimental accelerations for the Hybrid II dummy.

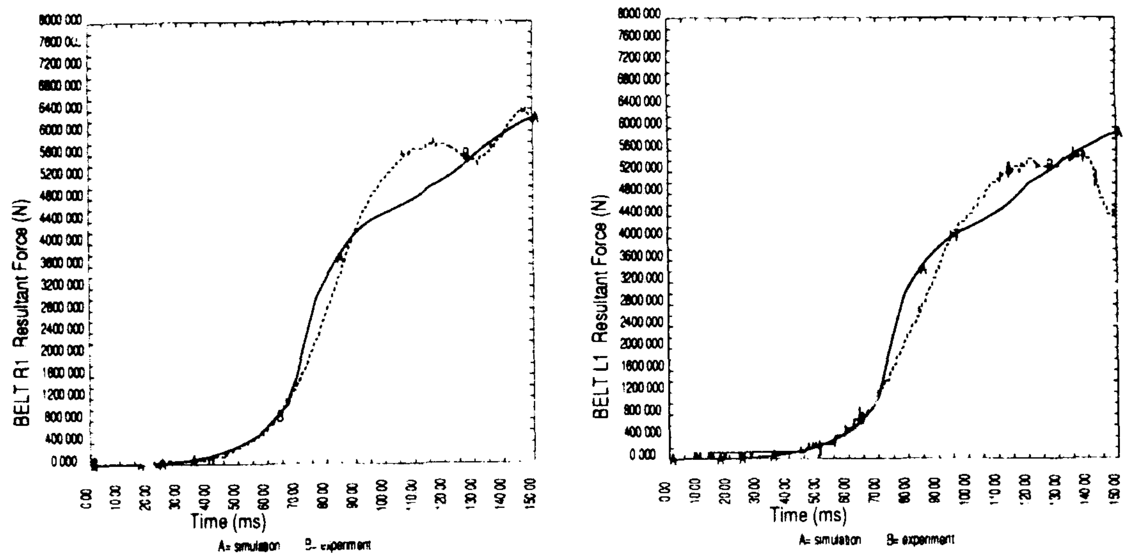

Fig. 14 Comparison between simulated and experimental forces in the belt restraining the Hybrid II dummy.

however, is always a complicating factor in this. For energy absorbing constructions often additional material is required, a strong reaction surface or structure is often desireble as well. A strong floor structure for example is an important starting condition for improving passenger safety on-board of civil aircraft. Another step could be to adjust the seat breakover stiffness, to incorporate an energy absorbing structure in the back of the lower end of the seat back and to cover hard parts which could interact with the occupant lower extremities with a padding. Special attention should be paid to passengers facing a bulkhead or galley, flight attendant (rearward facing) seats, pilot interaction with the environment, on-board child seats and equipment restraints.

From the research presented it can be learned that the current MADYMO version is suitable for simulating aircraft seat and passenger response during an actual crash or standard dynamic seat test. Since no seat structural deformation of importance was observed after the dynamic seat test presented here and no pre-deformed state for the seat legs was initiated (as prescribed in FAR Part 25) to start with, it was decided to model the lower part of the seat as a rigid body. When there is a predominant impact load component in the vertical direction, as in the "14 G dynamic seat test", a considerable deformation of the seat front tube and/or seat legs is likely to occur. In the latter case the lower part of the seat can be modelled with several rigid elements interconnected by joints. For this purpose the stiffness properties of structure components have to be translated into joint properties. The same holds for a pre-deformed state of the seat legs. Figure 15 illustrates a possible set-up for a deformable seat model, including four different joint types. Figure 16 shows another example of this so-called lumped mass modelling technique, a model of the side-structure of a passenger car. This model was used to evaluate the effect of vehicle modifications on the injuries assessed by the EUROSID-1 dummy sitting in the car [17].

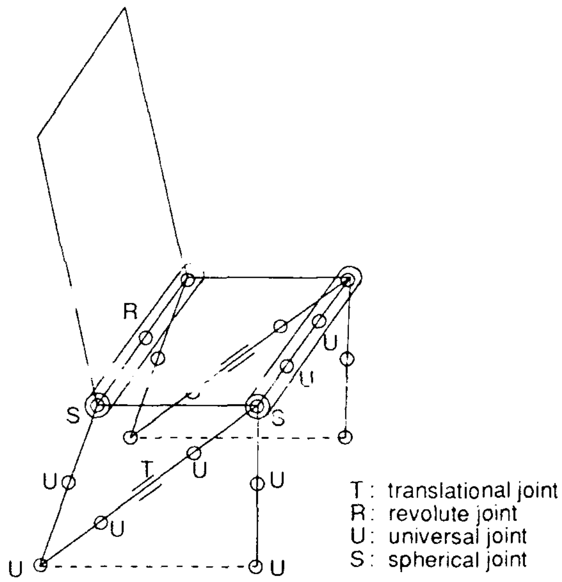

Fig. 15 Possible MADYMO model set up for a deformable aircraft seat.

Instead of the lumped mass approach for representation of structural deformations, a finite element model can be used. This approach has the advantage that deforming structures can be analysed more in detail, a disadvantage obviously is the fact that input file generation as well as the calculation itself take more time. So, parametric studies become more laborious. Future developments in both the multibody and finite element part of MADYMO are directed to offer the user an optimal analysis tool in this respect.

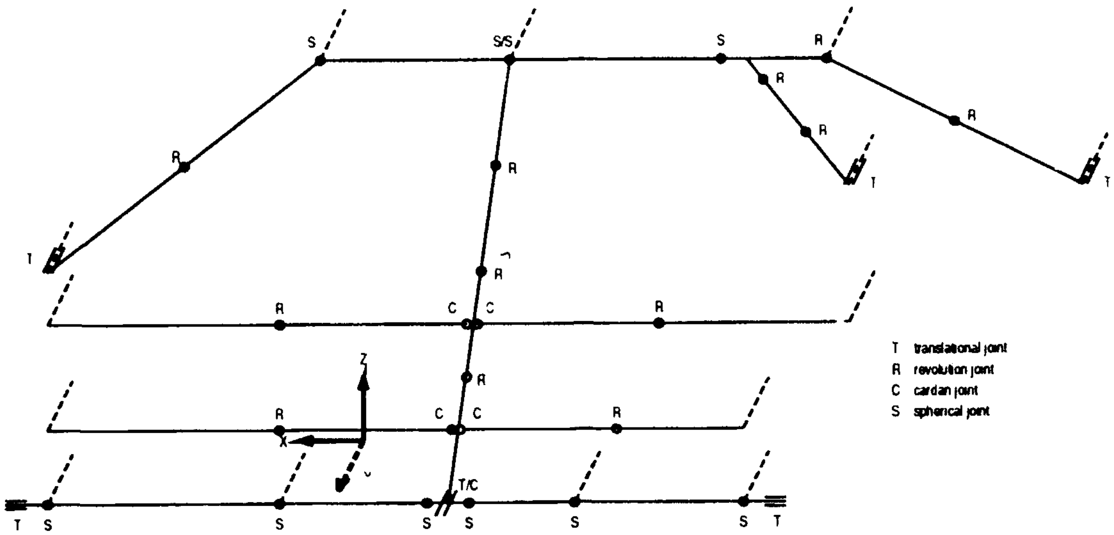

Fig. 16 MADYMO representation of the side-structure of a passenger car.

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Computer Aided Methods for Simulating Occupant Response to Impact Using OASYS DYNA3D

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SUMMARY

Numerical simulation can play a key role in design for crashworthiness and accident investigation. This paper presents recent work in the development of occupant simulation techniques for the automotive industry, and describes how the same techniques may be applied to aircraft crashworthiness

1.0 INTRODUCTION

In the automotive industry, recent work has focused on the development of an integrated approach to vehicle crashworthiness and occupant protection. Previously, several different analytical approaches were used during the design process. Lumped parameter, framework, finite element continuum and occupant models were all developed using different software packages. Frequently, different expert analysts were needed to drive each code and there was no means of establishing continuity or comparability between the different types of model.

Where occupants and structure are treated independently, however, a fundamental difficulty exists: the two systems interact in reality, and it is technically incorrect to model them separately. This is particularly true of vehicle side impact, in which the occupant interacts with the interior of the door structure. In vehicle frontal impact, knee-bolster design requires careful consideration of how the legs of the occupant influence the deformation of the bolster. Airbags provide a further example: the loading on the occupant arises from complex interactions with the bag.

This paper illustrates how one single computer program, OASYS DYNA3D, can now be used in a realistic fashion to address all of the important aspects of impact in a single three-dimensional simulation. Extensive quantitative correlation has been carried out against vehicle sled tests and the most useful results are summarised.

The techniques described below can also be applied to the aerospace industry. They may be used during the design process to optimise occupant protection features, and they may also be used during accident investigation to analyse the causes of occupant injuries.

OASYS DYNA3D (Ref 1) is based on the LS-DYNA3D program developed by Dr J O Hallquist (Ref 2). Dr Hallquist's pioneering work with LS-DYNA3D has been adopted by automotive manufacturers world-wide for crashworthiness applications. OASYS DYNA3D and its pre- and post-processors are Quality Assured and contain a number of unique features purpose-written for occupant-related analyses, e.g. occupant positioning software and new seat belt algorithms.

2.0 OCCUPANT MODELS

The use of numerical models for the analysis of occupant response is well established. The most common representation of a dummy is as a series of rigid ellipsoids. This section describes how recent work has developed structurally faithful models of biofidelic dummies.

2.1 Rigid Ellipsoid Models

In the simplest analytical simulations, occupants are often modelled as a series of rigid bodies representing head, neck, upper torso etc., linked together to form a mechanism. The rigid bodies are commonly ellipsoidal.

It is straightforward to represent occupants in this way using OASYS DYNA3D, since all the requisite features (rigid bodies, joints and rotational springs and dampers) are available. Figure 1 shows an OASYS DYNA3D ellipsoidal model of a standard automotive industry dummy (HYBRID III). The geometry, masses and inertias have been taken from published data (Ref 3).

The ellipsoidal representation does, however, have disadvantages when interaction with restraint systems is considered Belts or harnesses can slide off ellipsoids too easily or even become stuck in the 'valley' between two ellipsoids.

2.2 Geometrically Accurate Models

OASYS DYNA3D places no restrictions on the geometry used to build an occupant model, and the occupant 'limbs' do not have to be ellipsoidal. More accurate representation of a dummy's surface geometry is easily implemented, and the authors have developed a family of HYBRID III dummy models using data digitised from the dummies themselves. Figure 1 also shows three of the OASYS DYNA3D HYBRID III occupants - a large male (95th %ile), standard male (50th %ile) and small female (5th %ile). Intermediate sizes may also be generated.

Modelling of the dummy's correct surface geometry allows improved interaction with restraint systems. Sliding of a belt over the shoulder, for example, can be modelled more accurately.

2.3 Biofidelic Models

Although representation of the occupant as a series of rigid bodies is sufficiently accurate for many applications, there are occasions when a more rigorous modelling approach is required. In vehicle side impact, for example, the compliance of different dummy components is extremely important. Injury criteria can only be predicted with confidence if the internal structure of the occupant is modelled.

In a recent programme of work sponsored jointly by the Transport Research Laboratory and Ford Motor Company Ltd., the authors have developed an accurate, validated numerical model of the EUROSID 1 side impact dummy. Figure 2 shows the OASYS DYNA3D model of the dummy. The model is significantly more complicated than the rigid surface dummies shown in figure 1. Those components which are likely to deform during the side impact event have been modelled as non-rigid elements. (It is worth mentioning that OASYS DYNA3D was originally developed as a general finite element program for the dynamic analysis of non-linear three-dimensional structures, and has a wide range of models for deformable materials).

The development methodology used was to start with models of individual components, and to calibrate each component model against test data. An example of this is shown in figures 3 and 4. Rib injury is common in side impact events, and the EUROSID dummy has three separate rib units used to assess rib injury criteria. Figure 3 shows the finite element model of an impact test on a single rib assembly, and figure 4 shows the response of the rib under impact. In cases where existing test data was inadequate for correlation purposes, further tests were commissioned.

Once satisfactory performance was obtained from the component models, they were combined to form the complete dummy model. A further set of correlation exercises was then undertaken, including sled, impactor and drop tests. These allowed the interaction between components to be calibrated.

Figure 5 shows the simulation of a typical impactor test on a complete dummy model. The occupant is oriented in a seated position and struck by an impactor moving laterally. Figure 6 compares the predicted rib acceleration with test data. These results, used to assess TTI (Thoracic Trauma Index) injury criteria, could not be obtained in this way by use of a rigid body representation of the dummy.

3.0 RESTRAINT SYSTEMS

New algorithms have been written for OASYS DYNA3D to represent seat belt systems including sliprings, retractors and pretensioners. These were written with automotive applications in mind, and have been used extensively in vehicle crashworthiness projects. They can, however, be used for any belted restraint system such as a pilot harness or airline passenger lap belt.

The features can be included in simulations with negligible increase in computing execution times. This section describes the new features.

3.1 Belt Webbing

The belt webbing is represented by a series of one-dimensional tension only elements, with user defined force-elongation characteristics for loading and unloading. These characteristics may be derived from dynamic tests performed in the laboratory.

3.2 Sliprings

Sliprings play an important part in the performance of the belt. Material feeds through from the retractor section into the shoulder section, and from the lap section into the shoulder section, so motion at shoulder level results in tensioning of the whole belt including the lap section. For this reason it is inadequate to model the belt simply as a spring element attached to the D-ring and shoulder, the process of feed-through must be included. A slipring feature has been added to OASYS DYNA3D to represent this: belt elements can pass through the slipring, resisted by friction.

3.3 Retractors

The retractor adds significant compliance to the belt system: even when an inertia-reel retractor locks, webbing can still be drawn off the drum due to film spool effect.

The retractor feature in OASYS DYNA3D allows material to be fed from the retractor into the belt or reeled back into the retractor from the belt. Before locking, material is reeled in under constant tension; this allows initial form-finding to take place. Once locked, webbing may be pulled out according to a user-defined force vs pull-out curve.

3.4 Pretensioners

Pretensioners tighten the seat belt during the initial phases of a crash. There are two main types: those that act to rotate the reel of the retractor, and those that act to move the stalk anchorage rearwards.

In OASYS DYNA3D, both types can be represented. The retractor type is simulated by entering a pull-in vs time curve, while the stalk anchorage can be moved using a preloaded spring.

3.5 Weblockers

A pair of toothed cams grip the belt near the retractor to limit compliance due to spool-out. These devices are simulated by entering a stiffer characteristic for retractor pull-out.

3.6 Tearwebs

A length of belt is sewn up concertina-style; when the force reaches a given level the threads pull out, resulting in a controlled dissipation of energy. These features may be modelled by adjusting the stretch characteristics of the belt elements at the tearweb.

3.7 Interaction with Occupant

Contact between belt and occupant is achieved using the standard OASYS DYNA3D contact algorithms. In this way, sliding of the belt over the chest or off the shoulder can be represented. Surface stiffnesses are adjusted to represent the compliance of the different body regions of the dummy.

4.0 AIRBAG MODELS

Airbags are becoming increasingly common in automotive vehicles, especially in the United States of America. They are also found in some aircraft, particularly helicopters.

This section describes the approach to airbag modelling that has been adopted.

The principal concern has been to avoid excessive computer run times: since the models are intended to be used as a design tool, fast turn-around time is a big advantage. The number of elements used to represent the airbag must be limited to a few hundred, and consequently the unfolding process (which typically requires several thousand elements) cannot be simulated. However, in the majority of cases interaction between bag and occupant does not commence until the bag is fully inflated so the unfolding process need not be modelled. The approach employed by the authors has been to use a coarsely meshed pre-inflated airbag.

When the occupant is out of position and interacts with the airbag as it unfolds, a finer mesh is required. Hallquist (Ref 5) is currently refining the very complex contact algorithms which are required if this is to be done properly.

4.1 Bag Material

An isotropic 'smeared wrinkle' material model has been written to represent the bag. This adopts a simple but robust algorithm which has been found to work well. Although differences in warp and weft stiffnesses are ignored, the level of accuracy is appropriate to the level of modelling of the occupant.

4.2 Gas Representation

The presence of gas inside the bag is represented by pressure applied over the inner surface. Although OASYS DYNA3D contains the gas law algorithms developed by Hallquist (Ref 2), at this stage simple pressure vs time curves have been used. The curves were derived from pressure histories measured during actual sled tests.

5.0 OCCUPANT SPACE MODELLING

As well as modelling the occupant and safety features such as belts and airbag, it is important to consider the occupant space. The deceleration of the occupant space is the primary input to the crash event.

Occupant spaces may be rigid or deformable.

Surfaces such as floor pans, dash facia (in automotive vehicles) or bulkheads (in aircraft) would usually be modelled as rigid. Dedicated energy absorbing features such as knee-bolsters or seat pans (in vehicles) or other seats (in aircraft) would usually be modelled as deformable. They could be modelled explicitly using deformable elements, or as rigid planes with user-defined 'ride-down' characteristics.

Figure 7 shows the OASYS DYNA3D representation of the Hyge rig used in vehicle sled tests. A small number of rigid elements are used to provide contact planes. The whole sled is treated as rigid, except that the seat is free to translate vertically relative to the sled and the seat pan and knee-bolsters can translate normal to their surfaces All of these relative motions are resisted by non linear spring elements providing the 'ride-down' characteristics. The crash pulse is applied as a velocity input.

This sled model was used for the correlation exercises described in Section 6.0 below.

6.0 CORRELATION WITH TEST

Correlations have been carried out with vehicle sled test data for the following cases:

- 30mph Belted
- 35mph Belted
- 30mph Driver side Airbag
- 30mph Passenger side Airbag

In each case results from two sled tests were available

6.1 Belted Tests

Figure 8 shows a sequence of elevations on the sled at 0, 60ms, 90ms and 120ms for the 30mph belted test. Correlation with test results is given in figure 9 for chest and head resultant accelerations, head trajectories, and forces in the shoulder belt, lap belt and retractor. A similar correlation exercise was performed for the 35mph belted test

In general, results show good agreement. The discrepancies which arise may be partly due to the following factors:

- the chest compliance may be underestimated thus reducing the forward motion of the head.
- contact between arms and facia at 70ms is probably too severe. In reality the arms strike the edges of the foam which is used in the sled as a knee-bolster.
- the foot to floor contact is unrealistically stiff, causing spikes in the acceleration traces at around 40ms, particularly in the pelvis.

The time history post-processor OASYS T/HIS allows filtering of results to standard specifications (e.g. Channel filter Class 180), and calculation of HIC (Head Injury Criteria) and 3ms Clip values. For example the 30mph simulation showed HIC of 807 (against 710 and 652 from test) and Chest 3ms Clip of 41 (against 37 from both tests). Given the well-known variability of HIC values these results are considered satisfactory.

Run time was 150 minutes on a low cost workstation for a 140ms simulation.

6.2 Driver Side Airbag

Elevations of the sled are shown in figure 10. Chest and head accelerations are compared with test in figure 11.

Correlation is good for all variables including head acceleration. The analysis took 225 minutes to run to 140ms on a workstation. The processing times required for these simulations would be reduced significantly if run on a supercomputer.

7.0 FURTHER DEMONSTRATIONS

As mentioned in the introduction to this paper, a vehicle occupant often interacts with the occupant space in such a way that the occupant response and vehicle structure response need to be considered simultaneously. This is usually the case when the compliance of the structure (e.g. a knee-bolster) is of the same order of magnitude as the compliance of the occupant.

Figure 12 shows examples of the integrated approach to combined vehicle/occupant modelling. In figure 12(a), a sled model similar to those described in section 6.0 has been enhanced to include a finite element model of selected structural components. The velocity input to the sled has been replaced by a lumped parameter representation of the front of the vehicle, and the single rigid plane knee-bolster has been replaced by a detailed shell element representation. In figure 12(b), even more of the structure has been modelled explicitly.

Figure 13 shows a much more sophisticated analysis, in which a HYBRID II dummy has been included in a full shell model of the vehicle body. A model like this typically requires many hours processing time on a supercomputer, but allows the full and proper consideration of the interaction between vehicle and occupant.

One of the advantages of the integrated modelling approach is the ability to develop continually an analytical crashworthiness model as the design of the vehicle progresses. In the initial stages of design, a simple model will allow parametric studies to aid design optimisation. Towards the end of the design process, full vehicle models can support crash tests in the testing ground. The use of one single modelling approach throughout the design process can bring great benefits.

8.0 CONCLUSIONS

A single code, OASYS DYNA3D, which is already in use for vehicle structure analysis, has been shown to be capable of delivering realistic fully three-dimensional occupant simulations.

A broad analytical approach to occupant modelling has been developed. For some applications, a rigid ellipsoidal model will suffice. When interaction with, for example, belt systems is required, a geometrically accurate rigid model may be used. In cases where the relative stiffness of occupant and structure is similar, or where the deformation of dummy components is used to assess injury criteria, a more complicated model is available. At all levels of complexity, extensive correlation exercises have been performed successfully.

Correlations with sled test results are good for belt and airbag restraint systems.

Good results can be achieved using simple models which take relatively little computer time, even when airbags are involved.

A fully integrated calculation is possible, in which occupant, vehicle structure, restraint system, and the interactions between these items are present.

These techniques may also be used for aircraft occupant simulation - both as a design tool to optimise restraint systems and as an accident investigation tool to reconstruct occupant behaviour during impact events.

ACKNOWLEDGEMENT

Part of the work reported in this paper was carried out with the suport of the United Kingdom Department of Transport (Transport Research Laboratory).

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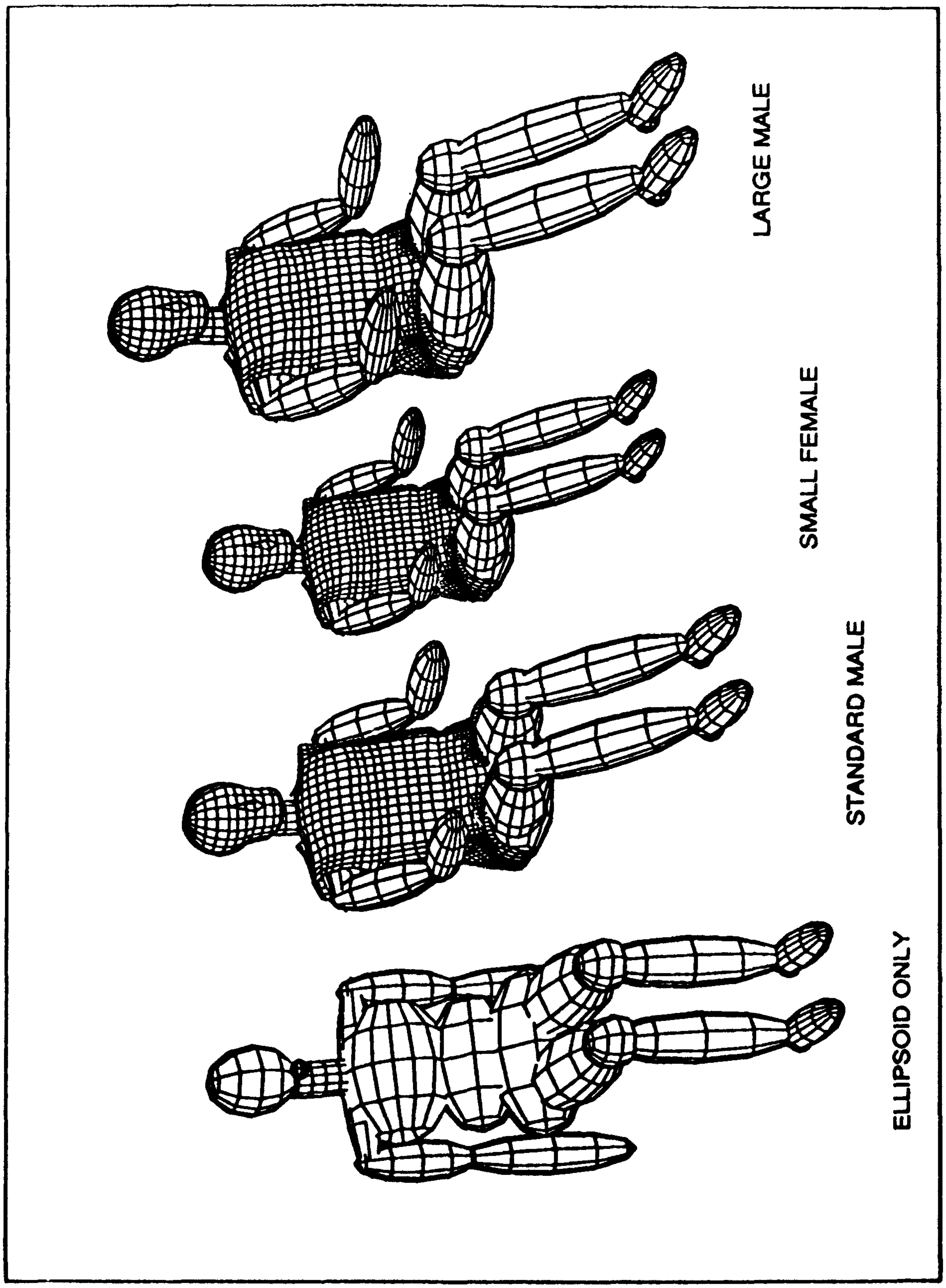


Figure 1. HYBRID III Dummy Models

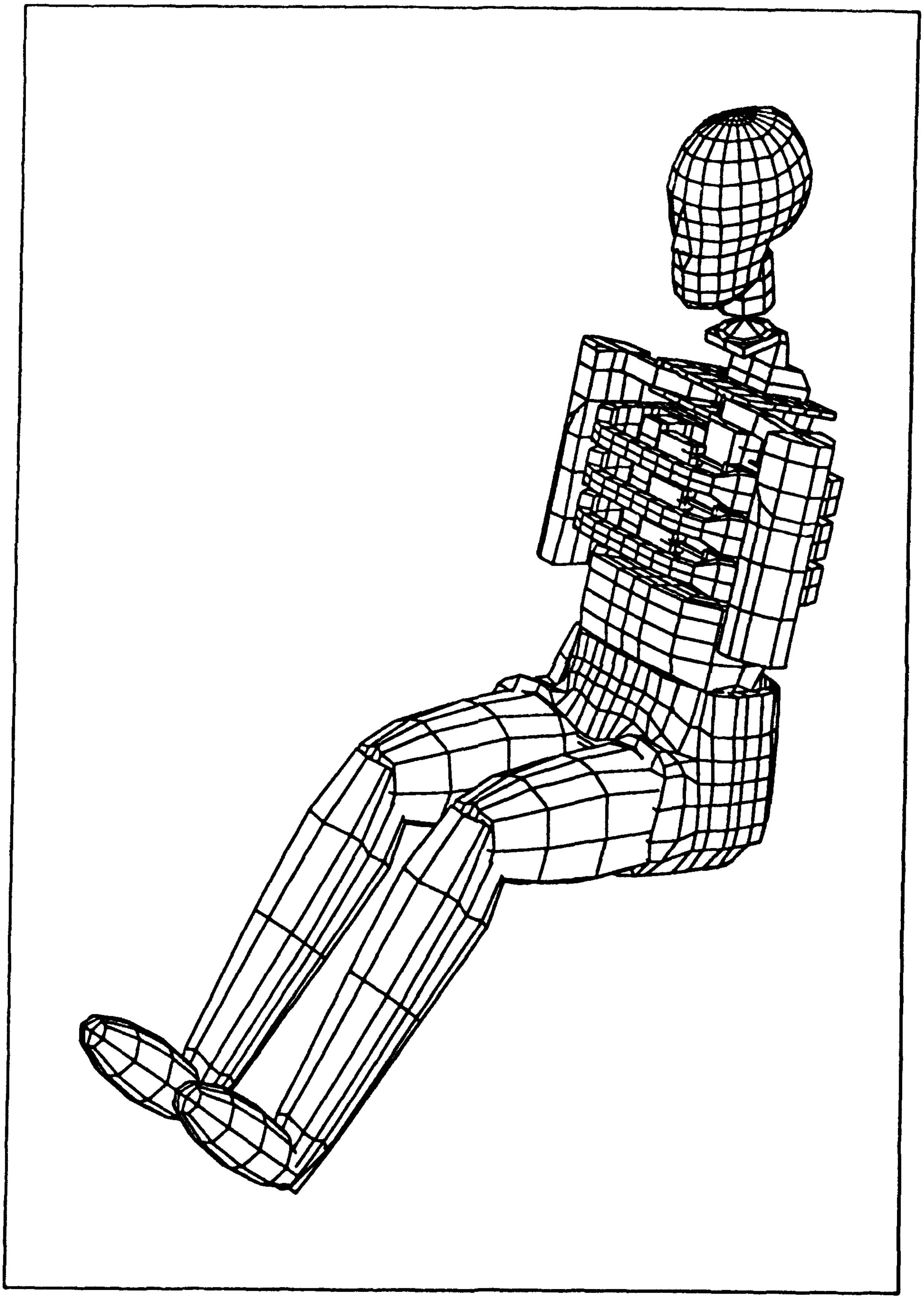


Figure 2. EUROSID Dummy Model

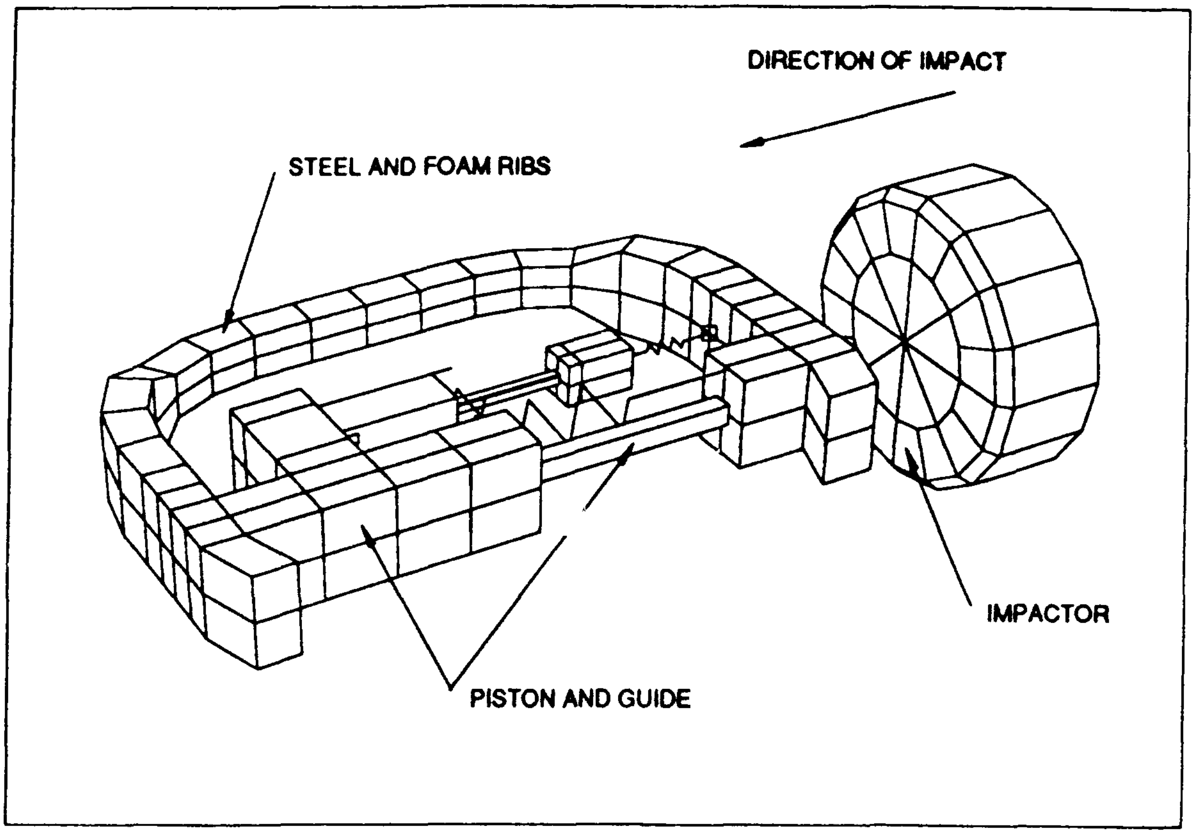


Figure 3. EUROSID Component Test - Rib Assembly

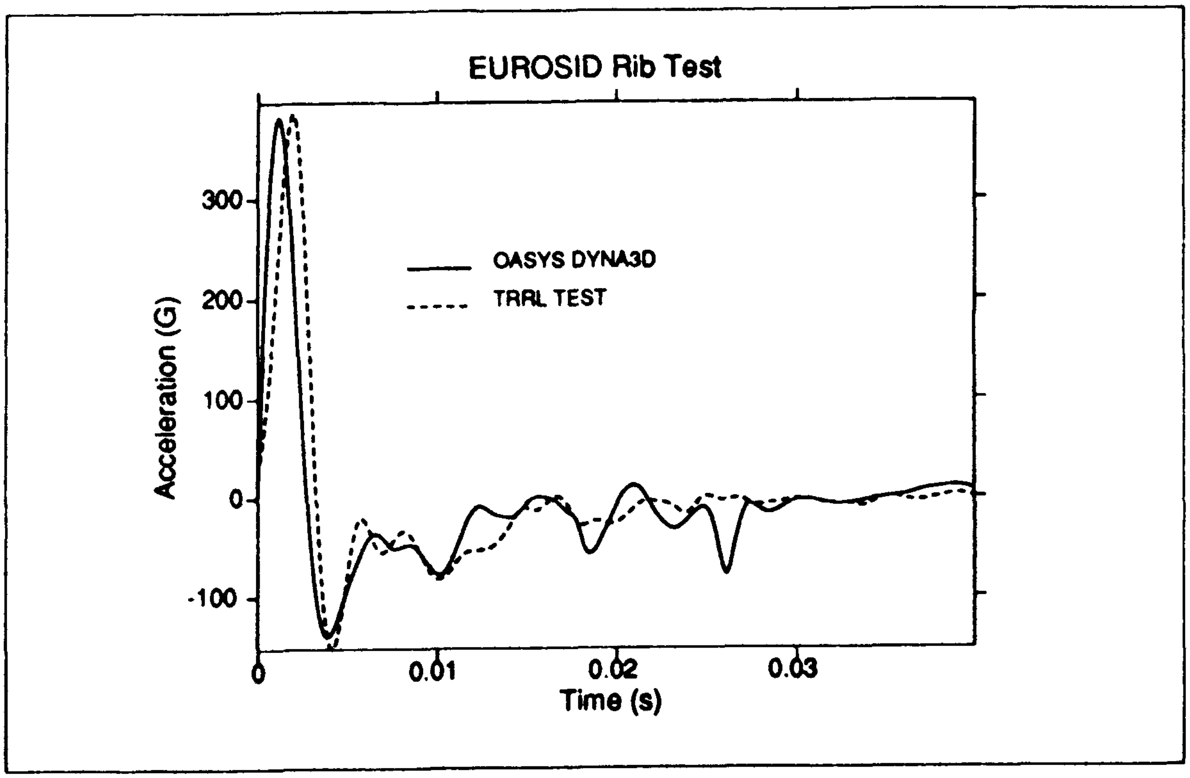


Figure 4. EUROSID Component Test - Correlation Results

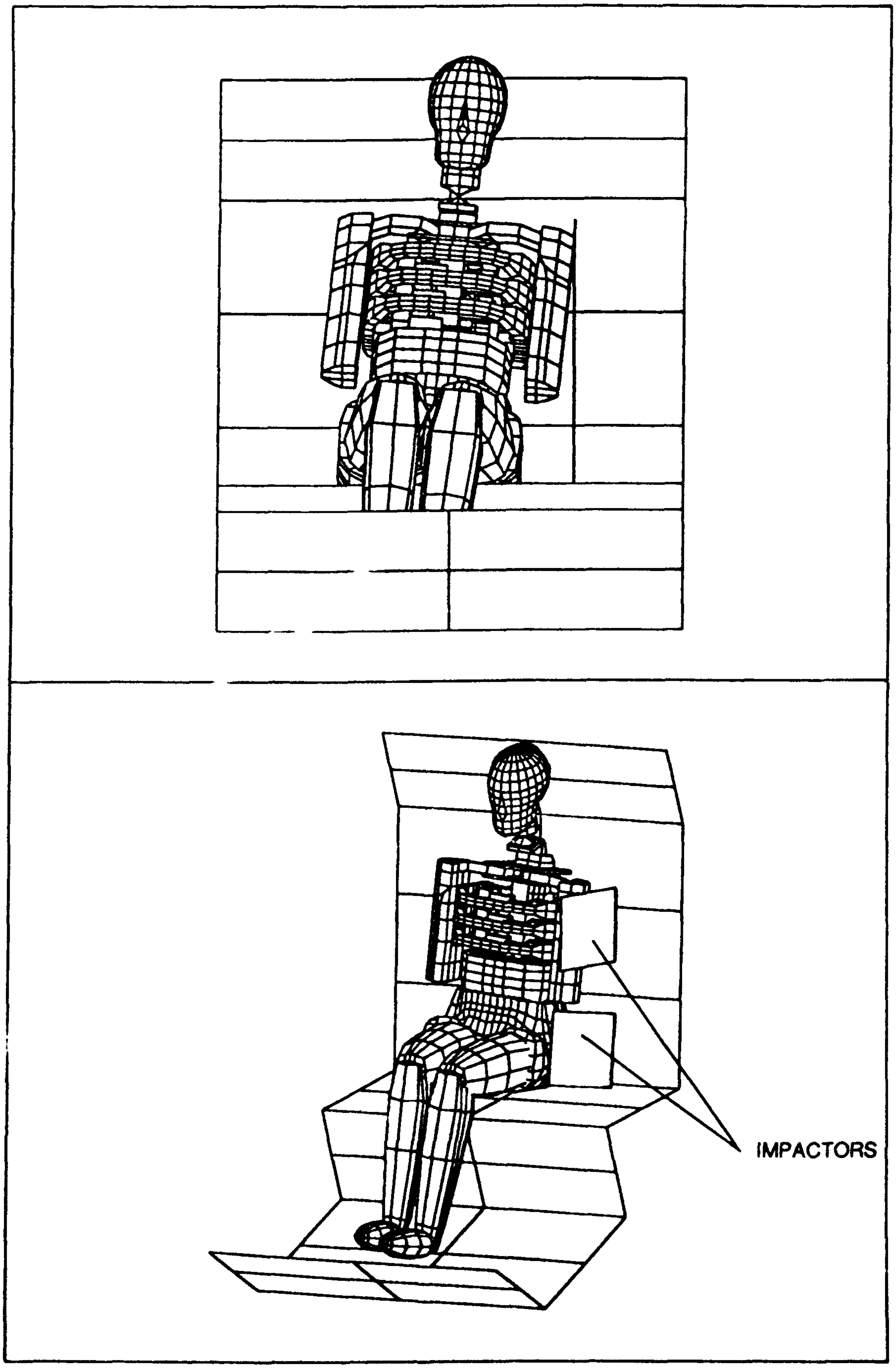


Figure 5. EUROSID Sled Test

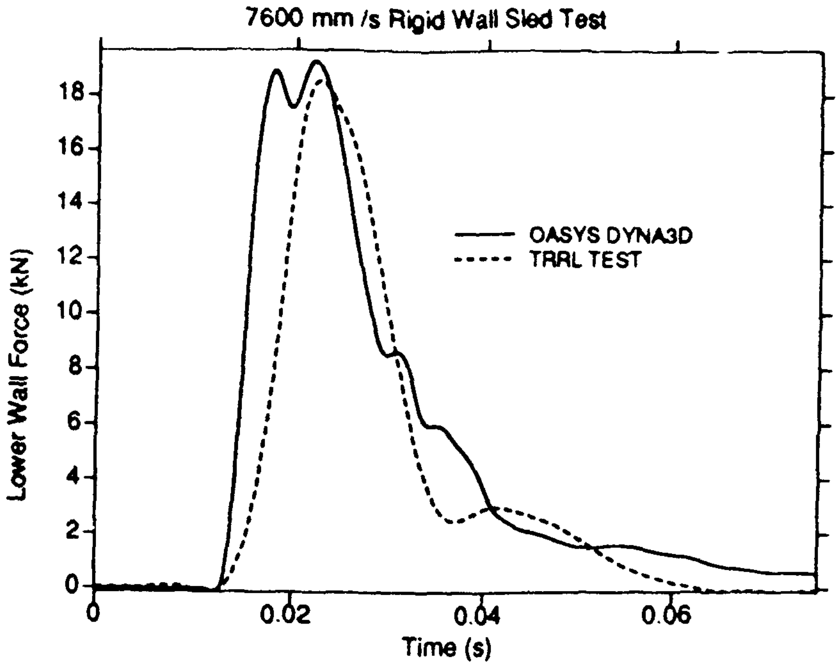


Figure 6. EUROSID Sled Test - Correlation Results

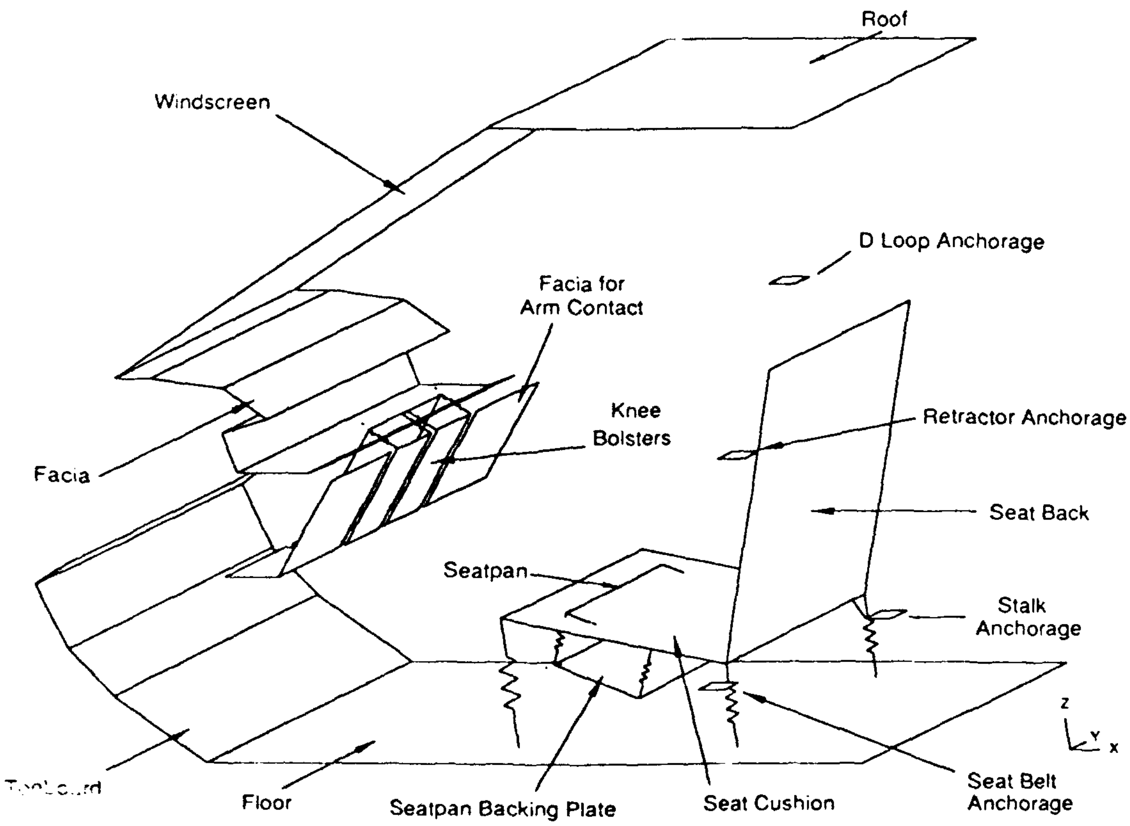


Figure 7. Sled Model.

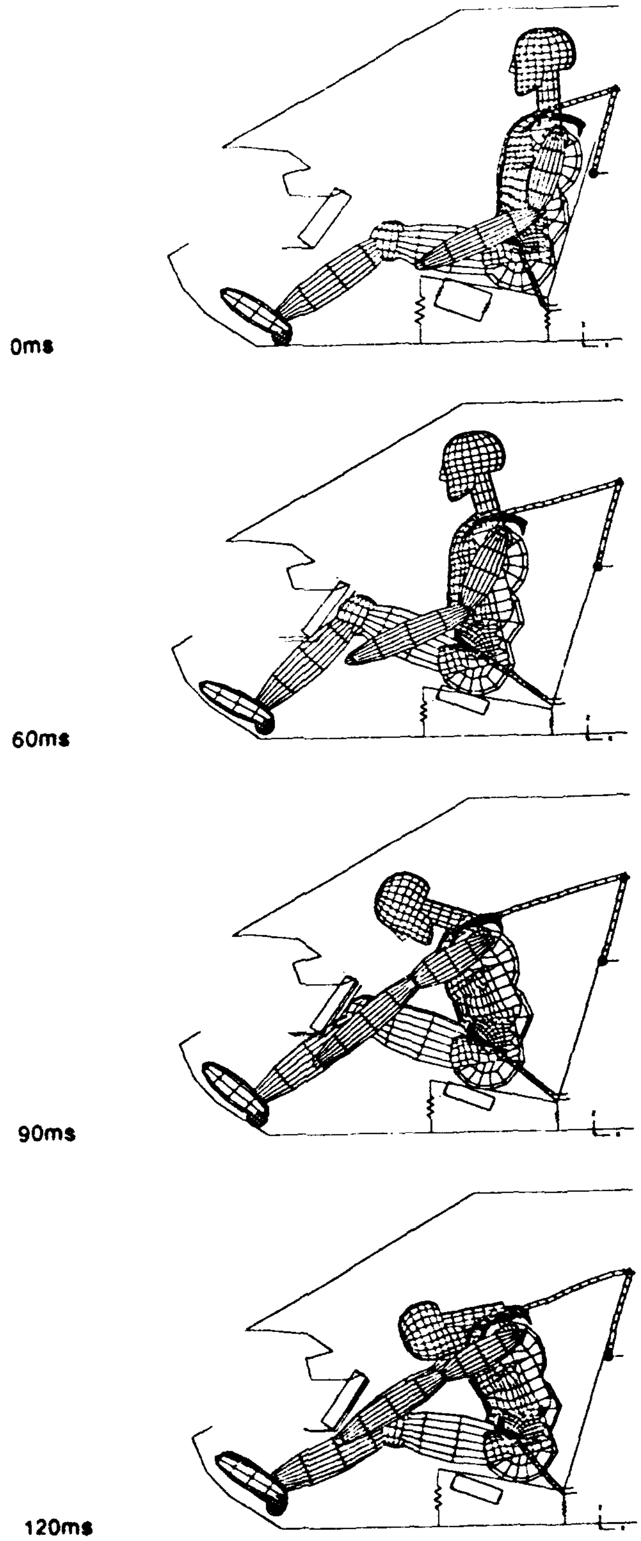
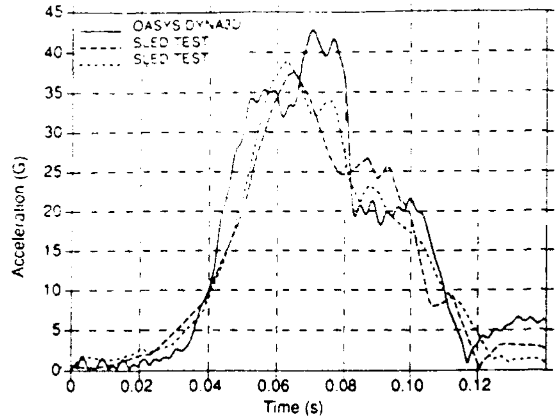
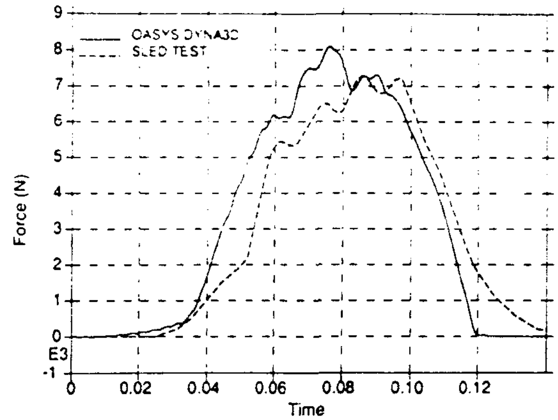


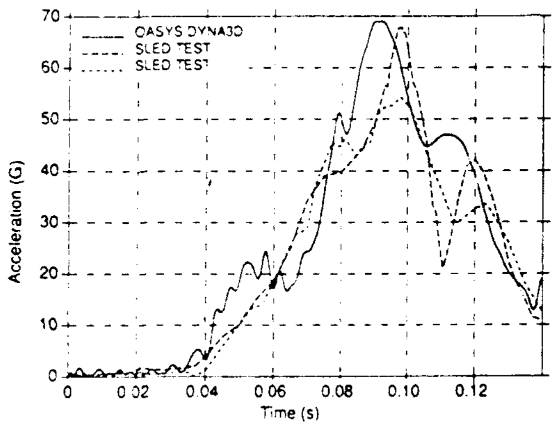
Figure 8. 30mph Belted Sled Test Simulation.



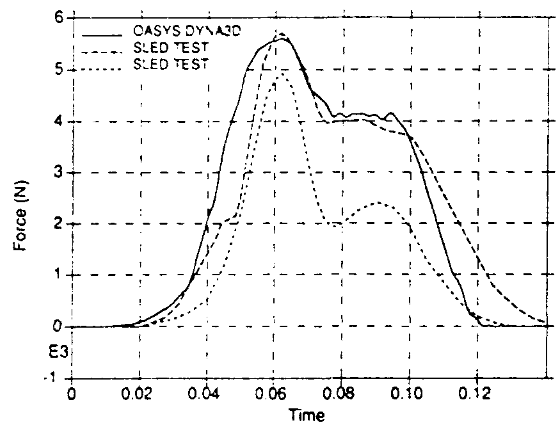
(a) Chest Resultant Acceleration



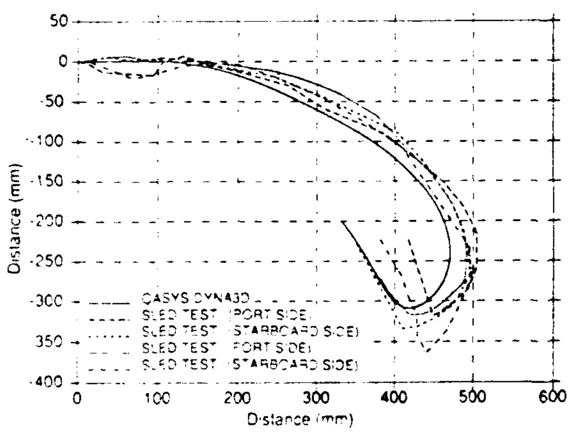
(d) Belt Force (Shoulder)



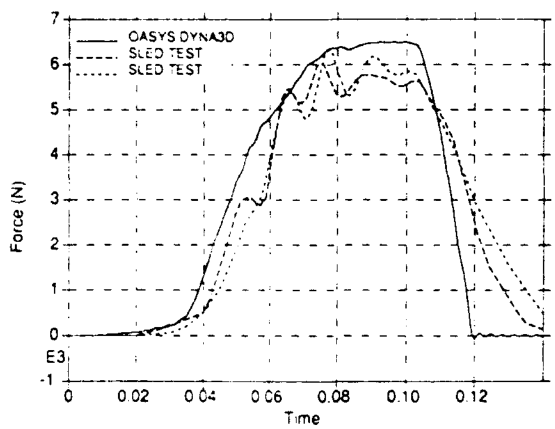
(b) Head Resultant Acceleration



(e) Belt Force (Lap)

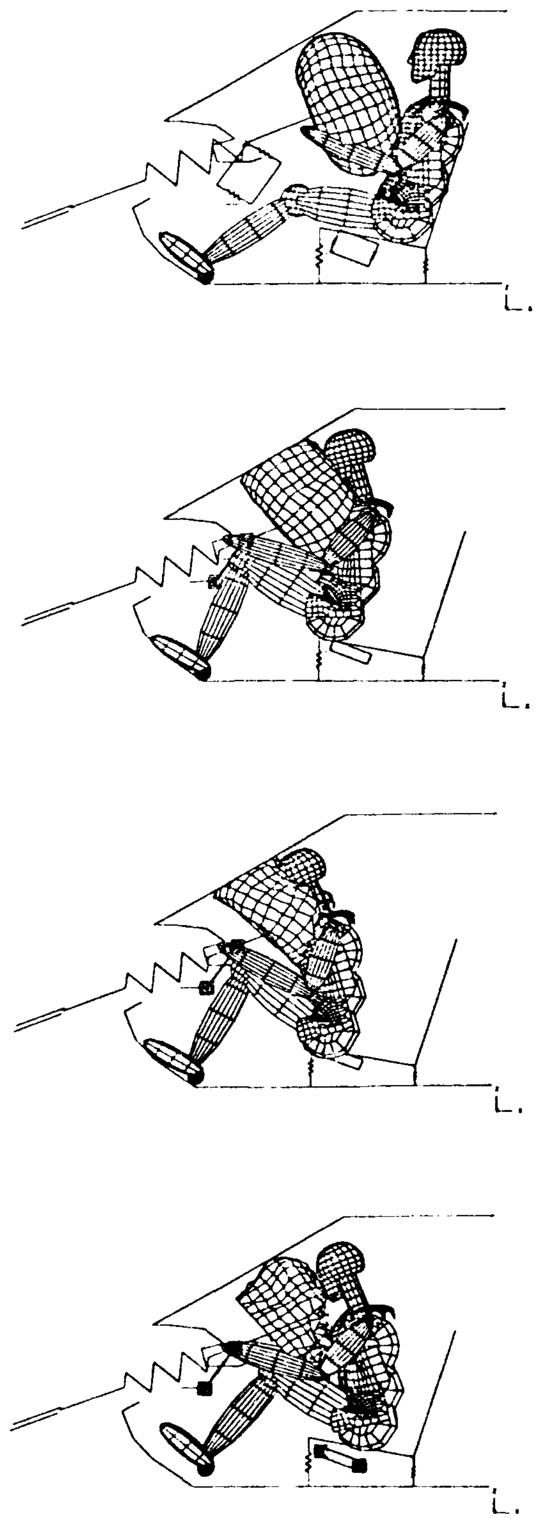


(c) Head Trajectory



(f) Retractor Force

Figure 9. 30mph Belted Sled Test Correlation.



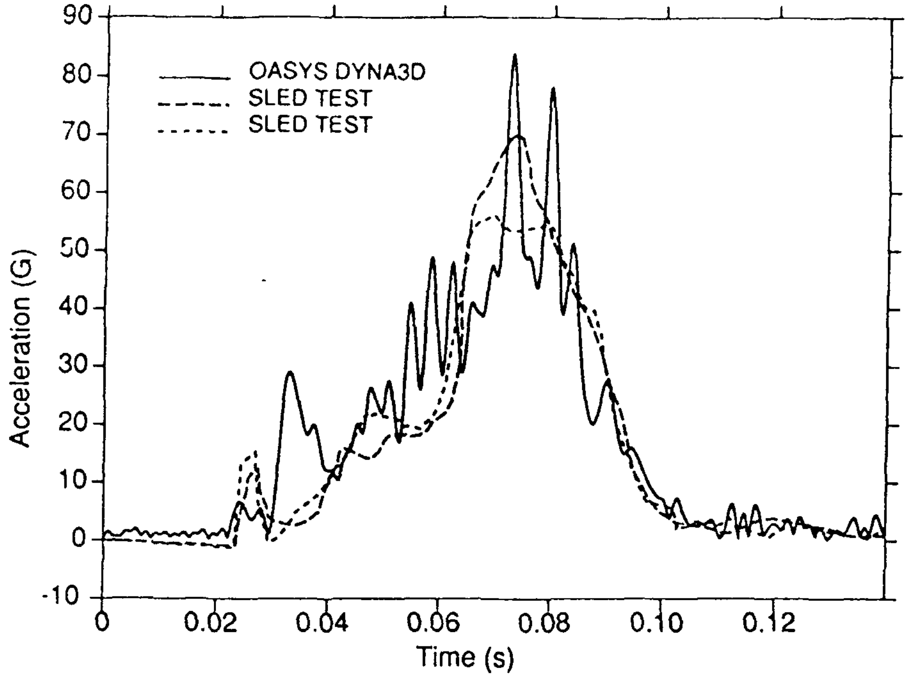
0ms

60ms

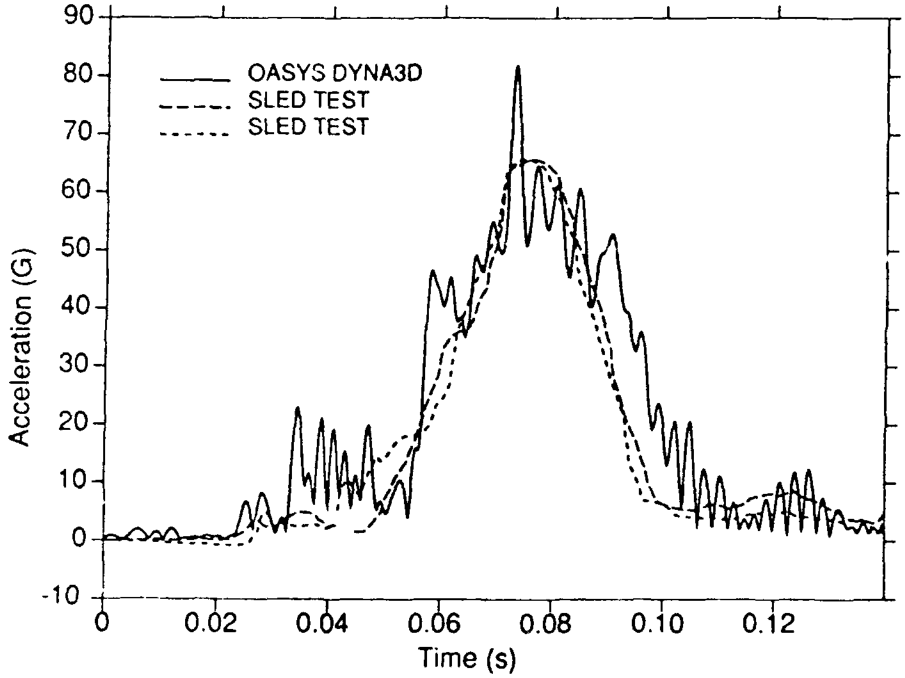
90ms

120ms

Figure 10. Driver Side Airbag Sled Test Simulation.



(a) Chest Resultant Acceleration



(b) Head Resultant Acceleration

Figure 11. Driver Side Airbag Sled Test Correlation.

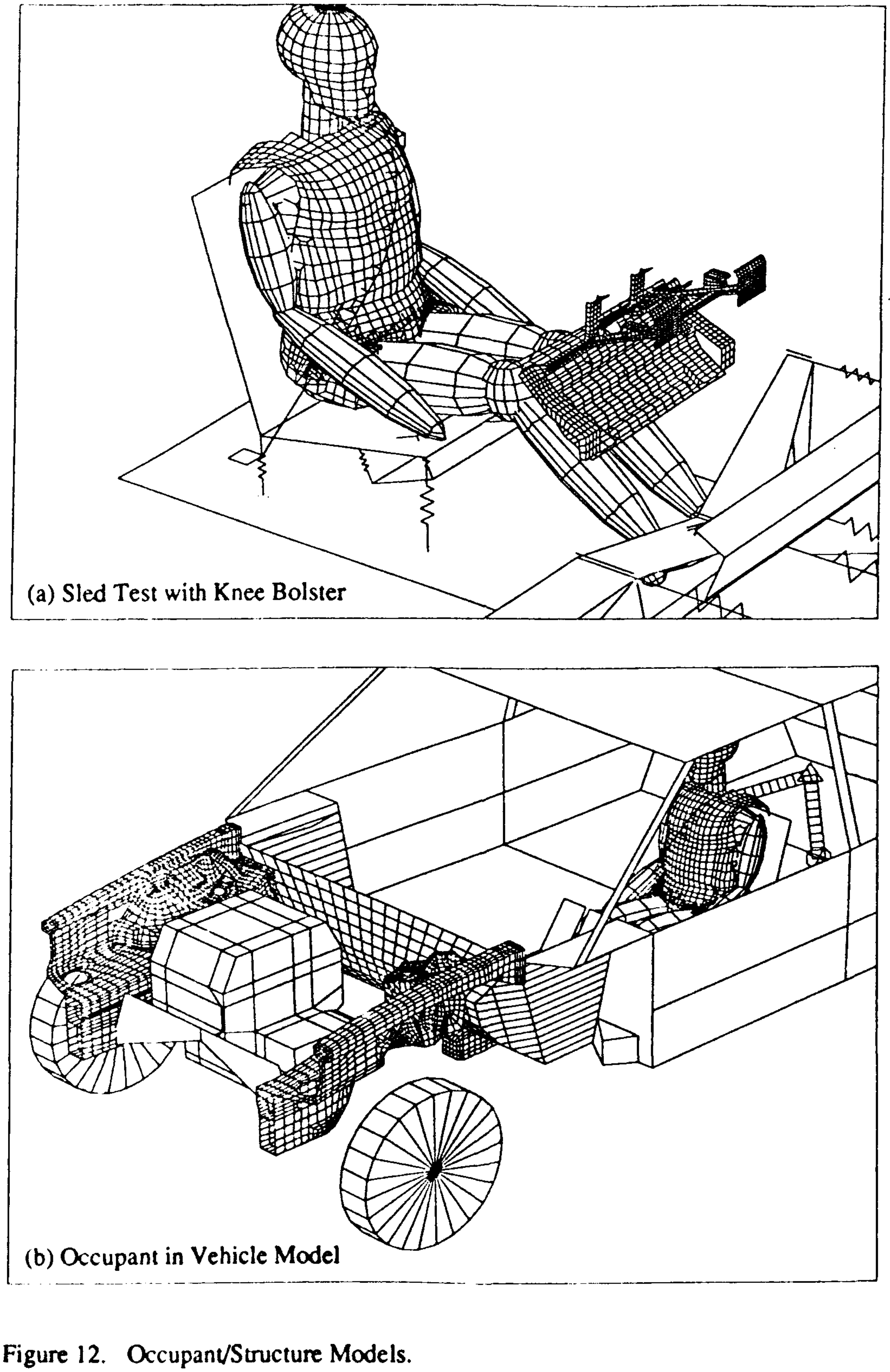


Figure 12. Occupant/Structure Models.

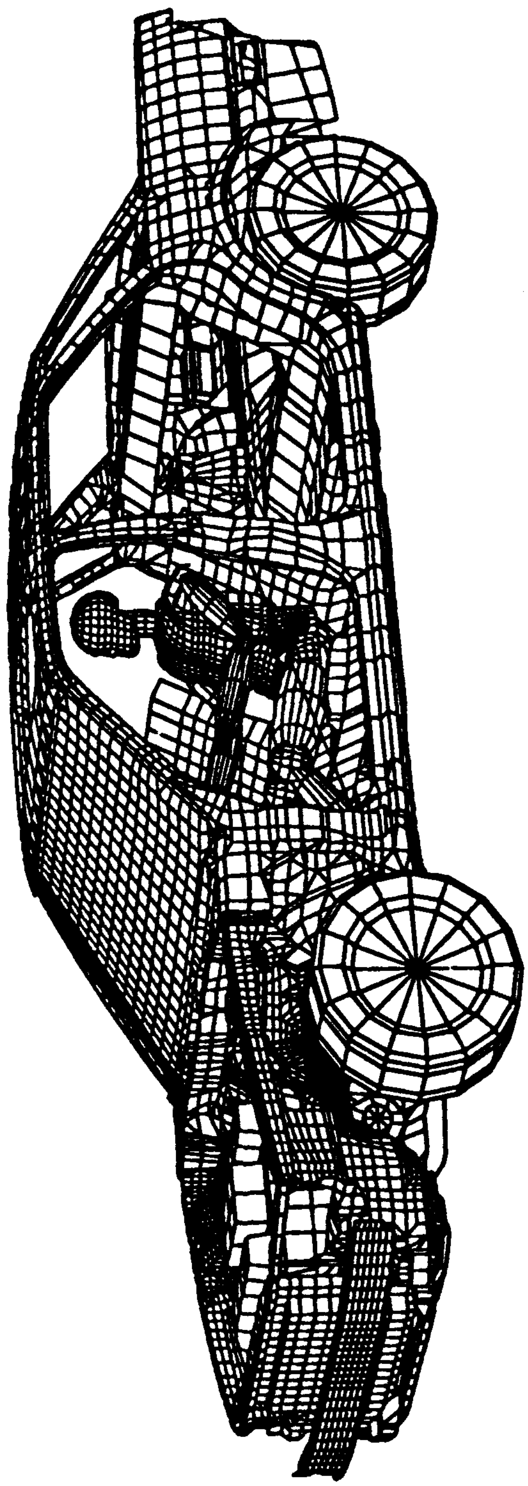


Figure 13. Combined Vehicle and Occupant Crash Model

Design & Development of an Enhanced Biodynamic Manikin

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Summary:

The research use of manikins for test and evaluation of escape and crashworhty seating systems, life support devices and a variety of safety equipment is well documented by the military and automotive communities. The manikin functions to load the aircraft or automotive seating system, interacting with the surrounding environment and optimally simulates human biodynamic response to transitory acceleration. Ideally, the manikin response closely approximates human responses, enabling direct comparison and correlation to known human test data. However, manikins provide only a partial correlation to humans, having limited biofidelity and biodynamic response. The requirement to measure and quantify the 3D response of the manikin have imposed significant electronics and instrumentation requirments, further complicating the attempts to provided improved biodynamic response characteristics to the manikin. Consequently, the new generation of advanced manikins must provide the biofidelity of its human counterpart, while concurrently supporting the instrumentation and high density, low cost electronics to measure and record the response dynamics.

This publication details the design and development of an enhanced manikin form incorporating all instrumentation and data acquisition capabilities to record and reconstruct the six degree of freedom response of the manikin. The manikin is designed to enhance biofidelity and provided a three dimensional biodynamic response, attempting to approximate that of the human. These objectives resulted in the implementation of an omnidirectional response flexible spine and pelvis assembly.

Introduction:
Historical Manikin Development:

The earliest recorded testing involving an anthropometric dummy was conducted by Start and Roth (1944) of Dornier Werke in the development and testing of an ejection seat for the DO335 aircraft. The dummy was a simple wooden form used primarily for ballasting the seat with representative body weights. The GARD-CG dummies, historically employed for escape system testing serve more as an instrumentation platform than a test article to quantify seat occupant interaction. Within the frame work of dynamic testing they provide a convenient structure to mount instrumentation and telemetry packages, provide ballast to alter seat acceleration profiles and are used to represent typical anatomical cross sections as subjected to wind blast and detection of deficiencies in the crew station clearance envelopes.

The advanced manikin forms of today (Hybrid III type manikin and the ADAM), represent the current technology in attempting to produce a biofidelic human analogue. The ADAM introduced a semi-flexible spine design, based on the conclusion that having an elastic spine in the vertical direction coupled to a buttock spring assembly, as created by a skin buttock covering would provide adequate simulation of the human spine to impulse loading in the vertical direction. The ADAM flexible spine, consists of a linear spring damper unit providing the upper torso damping, with pitch and roll motions of the upper torso with respect to the pelvis provided by a lumbar articulation mechanism.

The Hybrid III type manikin is a state of the art manikin, with human test data available for comparison. The Hybrid III has become the standard test article at various laboratories with promising results. The Hybrid III is a flexible manikin capable of three dimension response to an omnidirectional input, consequently exhibiting realistic interaction with restraint and seating systems under test. Work performed by Frisch [1,2] details the instrumentation and data acquisition capabilities incorporated into the Hybrid III along with functional and structural tests used to confirm manikin performance. As reported by Frisch [3], the Hybrid III 5% female, instrumented with an Aydin Vector MMP900 PCM system was successsfully ejected at 725 KEAS at the Naval Weapons Center, further demonstrating the Hybrid III capabilities.

The Hybrid III evolution can be tracked from the development of the Hybrid I by GMC. Its history, objectives and attributes closely parallel the advances attempting to attain a high degree of repeatablity and improved response. The Hybrid III head consists of an aluminum shell covered by a vinyl skin. The neck exhibits one piece biomechanical bending and dampling response in flexion and extension. The thorax consists of six ribs connected to a welded steel rigid steel spine. The spine provides for attachment of the neck, clavicles an the lumbar spine. The lumbar spine is a curved polyacrylate elastometer with molded end plates for mounting. A detailed description of the Hybrid III can be found in Foster (1977) [4].

Manikin Response Requirments:

In order to accurately reconstruct te three dimensional response of it human counterpart the manikin must not only support sufficient instrumentation, but must also maintain the flexiblity to mimic specific movement at key anatomic locations. The review of acceleration related injuries identifies the areas of most concern. The helicopter acceleration related injuries reviewed by Shanahan, as reported by Coltman [5], indicated the distribution of spinal fractures were, primarily, in the T11 to L4 region, with the highest incidence occuring at L1. Naval ejection seat related injuries (1969-1979), as reported by Guill [6] were concentrated in the T6 to L1 region, with principal modes at T7 to T8 and L1. Cervical injuries concentrated at C2, were also evident. A detailed review of spinal trauma and injuries from clinical and operational statistics as summarized by Karzarian [7], are illustrated in figure #1. As indicated the injuries are distributed throughout the neck, thorax and lumbar regions of the spine, requiring an improved analogue simulation than provided by the rubber lumbar and rigid thorax of the Hybrid III.

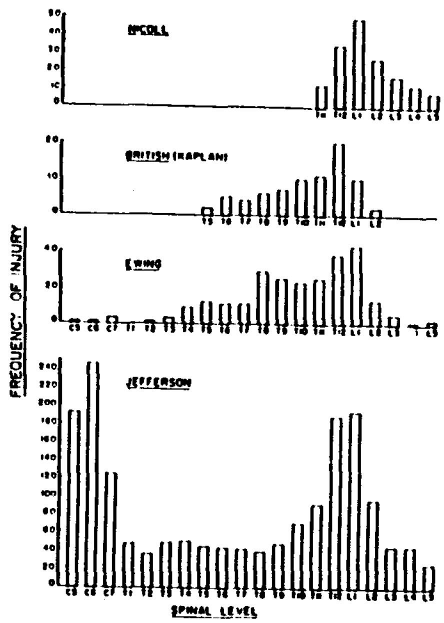


figure # 1

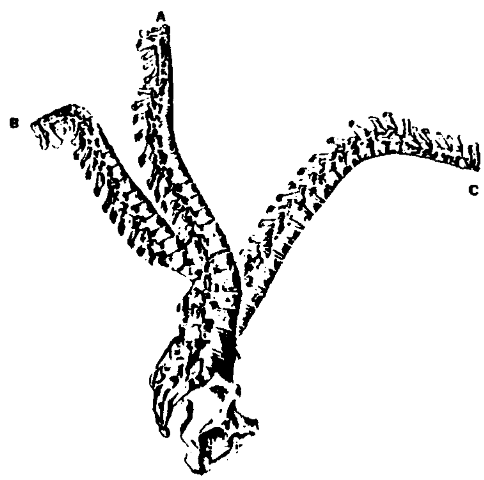


figure # 2

Consider the spine and midsagittal plane excursions illustrated in figure #2, as presented in the ADAM RFP [8]. The spinal contour under normal conditions maintains a "S" type of contour (a), the flexion and extension are illustrate as (b) & (c) respectively. One objective becomes the simulation of this type of response, while providing the mechanical integrity, repeatability (calibration) and compatibility with the existing manikin structure. Analysis of spinal contour as function of seated position indicated a broad spectrum of possible contours, based type of seat and general upright or slumpped positioning. Figure #3 illustrates the contour of the spine based on subjects seated in a typical mid-size automobile as reported by Department of Transportation (DOT) [9], while figure #4, illustrates a upright seated posture as extracted from a typical anatomy textbook. Clearly, the response of these configurations will vary considerably under acceleration. Based on these results a design parameter of the mechanical spine is to provide the capability to adjust the contour or intial position of the spine to conform with the seating position. Review of the spinal response to Gz acceleration as modelled by Beltyschko & Privitzer [10], indicates that spinal response is not only compressive in nature, but also represents changes *in contour as function of load. To accurately simulate spinal dynamics the mechanical analogue must also account for this type of response characteristic. The final parameter to be incorporated into the spine design requirment was axial rotation. The axial rotation of the human spine as detailed by DOT data [11], indicates a approximate +/- 60 degree axial response distributed along the lenght of the spine. In order to measure the spinal dynamics the instrumentation necessary to monitor the forces and moments at the specific anatomic locations must be an integral part of the spine design.*

The Enhanced Biodynamic Manikin:

The enhanced manikin as designed and developed by Applied Physics is shown in figure # 5. The manikin anthropometry is based on the 50 % aviator population as defined in the US Triservice Specification [12], and incorporates all sensors and data acquisition electronics as an integral part of the manikin. The manikin incorporates a flexible spine to provide a three dimensional response (flexion, extension, bending, compression and axial rotation). The spine mates with an anatomically representative pelvis, accurately locating the H-point, L5 location and the Illiac crest height, contour and position. The pelvis provides the structural housing incorporating all the signal conditioning and data acquisition and storage electronics.

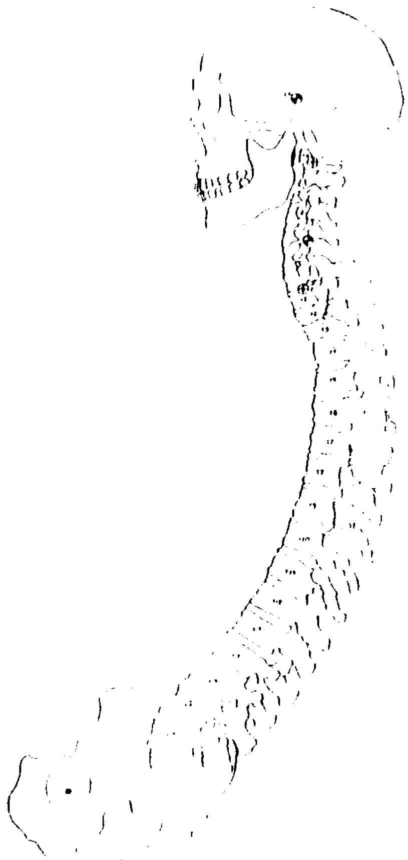


figure # 3

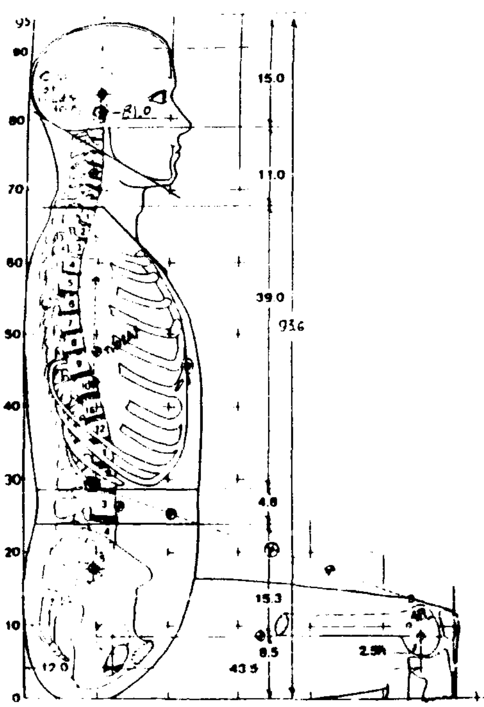


figure # 4

figure # 5.

Flexible Spine:

The detailed design of the flexible spine is illustrated in figure #6. The spine is divided into three distinct regions, the head/neck, the thorax and the lumbar spine. As shown the spine incorporates compressive and bending components in all three regions attempting to provide improved biodynamic response. In addition the spine incorporates multiple adjustment points enabling the inital contour of the spine to be altered. The head/neck assembly provides an adjustment mount similar to that of the original Hybrid III unit, where the head position can be prepositioned. The L5 adjustment bracket provides for the the intial positioning of the of the low lumbar spine, as necessary to conform to specific seating systems. Throughout the spine the unit implements an arrangement of exchangeable wedges to alter the overall spinal contour or "S" shape of the spine. The use of these wedges ensures a constant initial positioning of the spine based on the wedge compliment utilized.

The head and neck assembly is based on what is referred to as the ADAM head and neck (Hybrid II head coupled with a Hybrid III neck). The head and neck attachment point corresponding to the occipital condyles (OC) location is instrumented with a six axis load cell, enabling the measure of the force and moments at this representive anatomic loaction. The base of the neck integrates with adjustment mount, enabling the initial position of the head to be adjusted over a +/- 7 degree range. Similarily, the base of neck, via the adjustment mount is instrumented with a six axis load cell. The thoracic region consists of a shoulder mounting assembly (enabling the use of the existing Hybrid III arms) integrating with an axial rotation mechanism and four modular mechanical vertebra. A secondary axial rotation mechanism is provided at the base of the thoracic vertibra. Each of the mechanisms provide a +/- 30 degree rotation capability, resulting in the +/- 60- degree rotation over the length of the spine. The thoracic vertebra (1 inch heights) provide the compression and bending features of the thoracic region. The thorax incorporates two adjustable cables through the vertebra to the top wedge where adjustments can be made to alter the response over this region. The lumbar region mounts to the thorax via a six axis Denton load cell at the approximate L1/T12 loaction. The lumbar spine consists of two modular vertebra (2 inch heights) and interfaces to the L5 adjustment bracket. The bracket mounts to a six axis load cell interfacing to the pelvis at L5, measuring the pelvic loads. The lumbar region also utilizes two calibration cables enabling the adjustment of the lumbar region response characteristic.

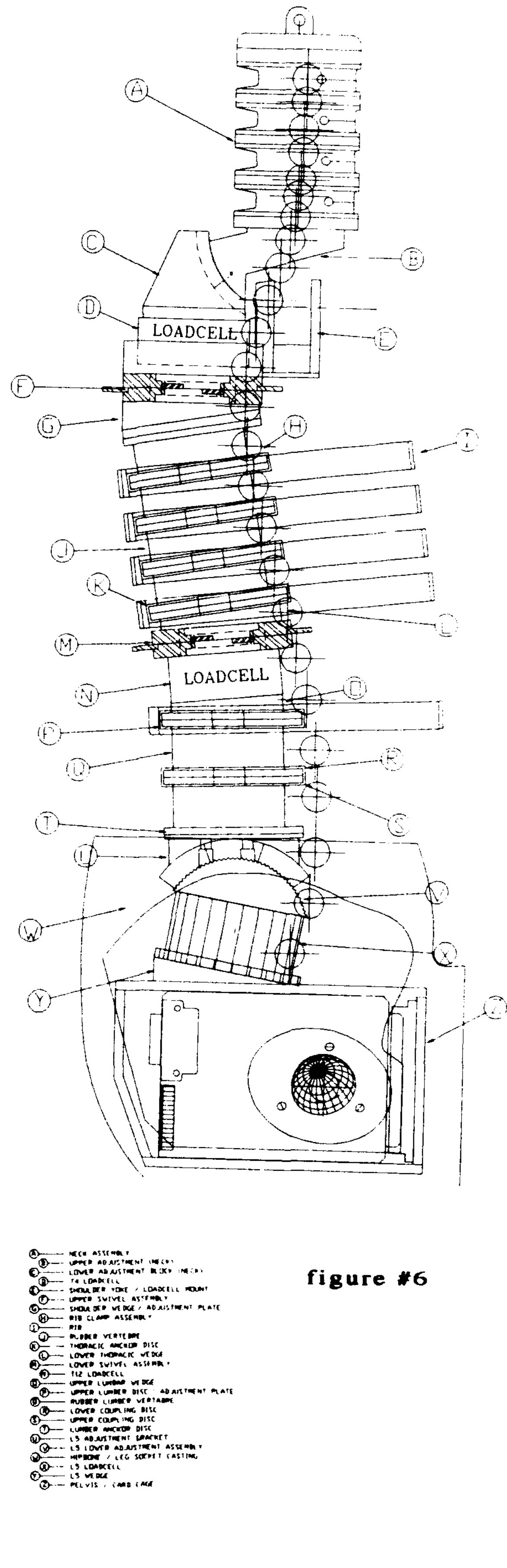
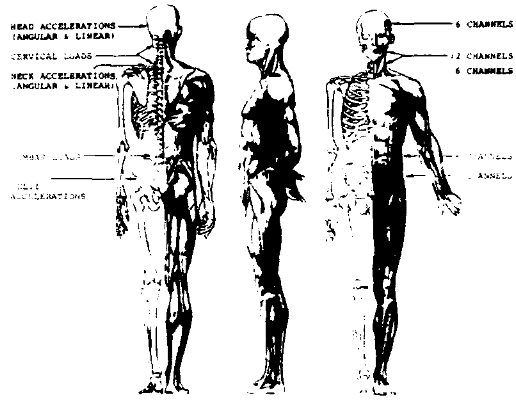


figure #6

Electronics /Instrumentation:

The abilitiy to mechanically approximate or simulate the dynamic response of a human requires sufficient onboard electronics to measure, record, quantify and reconstruct the six degree of freedom response of the manikin. Only through detailed comparison of response data to known human data bases can the mechanical response be validated.

As before the injuries as reported by Coltman [5] and Guill [6], become the driving function for the determination of sensor and instrumentation requirements. Monitored manikin response at key anatomic locations correlating to high injury probablity must be obtained in sufficient degrees of freedom to make effective analysis possible. The typical instrumentation requirment is illustrated in figure #7. Both linear and angular acceleration components must be available to fully define the dynamic response of any rigid anatomical segment, such as the head, T1 and pelvis. Additionally, since compression, flexion, extension, rotational forces and moments are utilized to gain insight into injury mechanisms. Inclusion of such measures at critical locations is considered a basic instrumentation requirment. The basic instrumentation options, sensors and tradeoffs have been documented by Frisch [13]. Table # 1 details the sensor configuration implemented within the manikin along with the expansion to be added at a later date.



Standardized Biofidelity Manikin Instrumentation

figure # 7

Channel 1	Head, Lin. Accel	
Channel 2	Head, Lin. Accel	Located at head c.g.
Channel 3	Head, Lin. Accel	
Channel 4	Head, Angular Accel	Located near head c.g.
	Head, Angular Accel	Provide angular accel
	Head, Angular Accel	connectors only
Channel 5	C-C, Force along Z Axis (F)	Located at centroid
Channel 6	C-C, Force along X Axis (F)	of C-C joint
Channel 7	C-C, Mom about Y Axis (M)	
	C-C, Mom about Z Axis (M)	
	C-C, Force along Y Axis (F)	Load cell connectors
	C-C, Mom about X Axis (M)	only
Channel 8	C-T, Lin. Accel along X (A)	Locate at forward
Channel 9	C-T, Lin. Accel along Y (A)	edge of vertebra
Channel 10	C-T, Lin. Accel along Z (A)	centrum
Channel 11	C-T, Force along Z Axis	
Channel 12	C-T, Force along X Axis	Locate at spinal
Channel 13	C-T, Mom about Y Axis	column centroid
Channel 14	C-T, Mom about X Axis	
	C-T, Force along Y Axis (F)	Load cell connectors
	C-T, Mom about Z Axis (M)	only
	T-T, Provide space only for easy retrofit (6-channel load cell)	
Channel 15	Sternum X displacement (S) at T attachment point	
Channel 16	Sternum Lin. Accel A	Locate at T intercept
Channel 17	Sternum Lin. Accel A	with sternum
Channel 18	L-S, Force along Z (F)	
Channel 19	L-S, Force along X (F)	Locate at spinal
Channel 20	L-S, Mom about Y axis (M)	column centroid
Channel 21	L-S, Mom about X axis (M)	
	L-S, Force along Y (F)	Load cell connectors
	L-S, Mom about Z (M)	Only
	L-S,-A,A,A Lin. accel	Mount provisions only at forward edge of vertebra centrum

- Linear accelerometers, ±100 g for torso
  Linear accelerometers, ±500 g for head
- Angular accelerometers, 12,000 rad/sec²
- Force/load values

  Lower spine compression, 4,000 pounds
  Upper spine compression, 2,000 pounds
  Leg bone compression, 3,000 pounds

SENSOR INSTRUMENTATION

table # 1

Data Acquisition and Storage System (DASS):

Study of the manikin anatomic geometry and spacial distribution, indicated two main volumes useable for the required electronics envelopes, the chest cavity and the pelvis. An earlier Applied Physics system (Navy Contract N62269-C-84-0207) [1], a 96 channel data acquisition and storage system, was retrofit into a 50th percentile Hybrid III chest cavity. The electronics though functionally, successful introduced limitations to the biodynamic response of the Hybrid III. Chest deformation was reduced to almost zero, manikin weight distribution and CG were alterd due to the inclusion of electronics and large NiCad battery assembly. The subsequent Air Force "ADAM" development [14], introduced a flexible spine (mid-sagittal response) with an on-board 128 channel data acquisition system. As in the Hybrid III the chest mounted electronics limited chest deformation, however, the manikin provided improved CG location and weight distribution.

The current strategy focussed on redistributing the electronics within the manikin, thereby not limiting the biodynamic response capabilitites. The implementation of the flexible spine and the resultant 3D response envelope precludes the introduction of any electronics into the chest cavity, with the exception of transducers.

The pelvis located at approximately the center of gravity of the human body, typically provides a large useable mass and volume within the manikin. However, to achieve an optimized interaction of the manikin with ejection or crashworthy seating systems or other safety equipment, the pelvis geometry, weight, and volume must be representative of the target population of interest.

Based on the work of Frisch [15,16], where a comparative study of human and manikin pelvis geometry, contour, and weight distribution was performed, it was demonstrated that sufficient electronics could be housed within the pelvis volume, while still maintaining a realistic anatomic representatiion. Based on the pelvis parameters as detailed within the Triservice Specification [12], an anatomic representative pelvis was designed to house the enhanced manikin integrated data acquisition and storage system, as illustrated in figure #8. The pelvis super-structure is based on a welded steel box, housing all the modules and integrating with an aluminum casting of the pelvic contour and socket. The cast contour provides the anatomic accuracy locating the key point of the pelvis relative to each other (L5 position, socket location H-point and Illac crest contour and height) The design provides for the constant box electronics structure, coupled with casting designed to match specific population and percentile groups. The system (DASS) as housed within the manikin is illustrated in figure #9, consisting of a 40 channel analog subsystem, and high speed processor subsystem providing real time data acquisition and data storage, and a femur mounted battery assembly. The system is supported by a user interface implemented via a dedicated IBM laptop computer to define and setup system function, channel configuration (gain,filter cutoff, etc), extract data, perform calibration, and to process and review manikin response.

figure # 8.

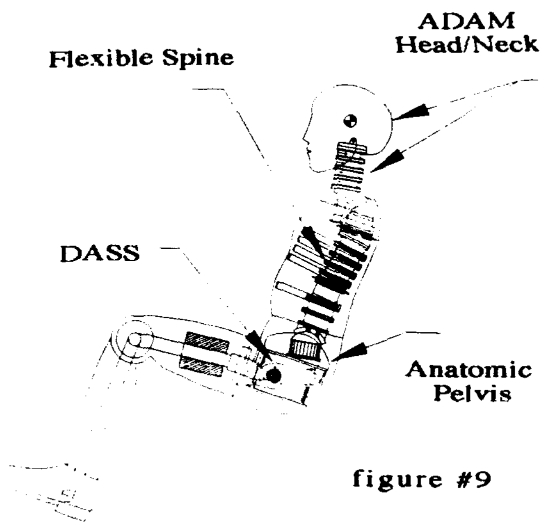


figure #9

DASS Architecture:

The overall system architecture is illustrated in figure #10, as consisting of a analog subsystem, processor subsystem, battery assembly and a PC laptop user interface. The processor component provides the CPU, data storage, analog electronics control logic and communications electronics, used to interact with the IBM based user interface. The analog subsystem provides 96 channels of analog signal conditioning and A/D conversion electronics digitizing the analog measured dynamic response parameters. The battery assembly provides all the necessary power to the DASS, and supporting transducers. The user interface consists of an IBM 386 DX laptop computer or compatible, enabling user control and interface to

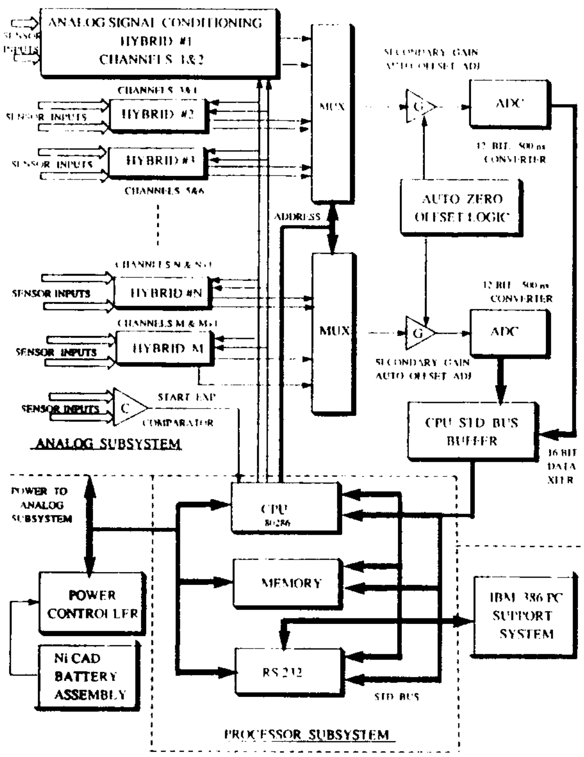


figure # 10

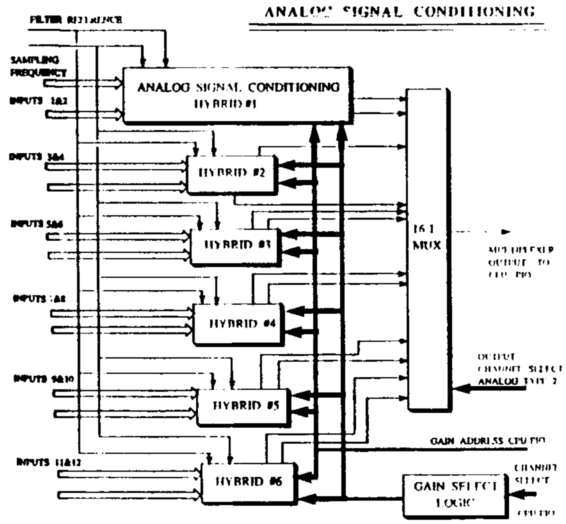
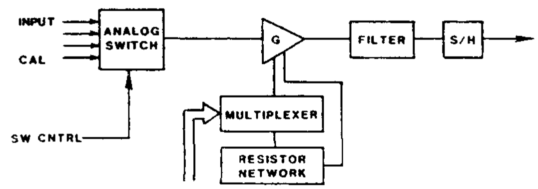


figure # 11

the manikin based DASS system. The laptop operates a "Windows" type interleaved software package enabling the user to easily interact with the DASS software.

Analog Subsystem:

The analog subsystem provides upto 40 channels of analog signal conditioning partitioned into 20 channel modules as illustrated in figure #11. The basic component of analog subsystem is the dual channel hybrid circuit developed by Applied Physics. A block diagram of a single channel of a dual path hybrid is illustrated in figure #12. As shown the hybrid consists of a switching network (AD7502) to enable the hybrid to except both transducer signals or simulated substitute voltages. Additionally, this network provides the capability of switching in an RCAL resistor used to offset the piezoresistive bridge type of tranducers verifying sensor operation and calibration. The sensor outputs are input into an Analog Devices AD625 precision instrumentation amplifier coupled with a multiplexer / resisitor network enabling the CPU to program eight (8) discrete gains (1,2,4,,10,20,25,50,100). This new Analog Devices amplifier elliminates gain errors introduced by the multiplexer "ON" resistance. This



SINGLE CHANNEL OF QUAD SIGNAL CONDITIONING HYBRID.

SPECIFICATIONS:

PROGRAMMER GAIN	1 TO 100
FILTER CUTOFF	MAX 20KHz
FILTER ROLLOFF	42 dB/OCTAVE
SAMPLING FREQUENCY	MAX 10KHz
PROCESSOR	HIGH-DENSITY HIGH PERFORMANCE SILICON GATE (HCNOS): - BIT
OPERATIONAL VOLTAGE	5V TO 5.5V (MICROCOMPUTER) 5V TO 15V (SIGNAL CONDITIONING)

figure # 12

resistance is biased out by use of the +/- sense inputs on the amplifier. A secondary gain stage has been introduced to increase the life cycle of the hybrid circuit design. Through the use of a board mounted resistor a secondary gain can be introduced in the analog signal conditioning path handling sensors not currently or commonly utilized. This enables a gain other than one of the discretes to be used. The amplifier network is connected to a low pass anti-alaising filter providing a -45 db/octave roll off. The filter network is based on the switched capacitor technology (SCF) allowing the variation of filter cutoff, by varying a reference frequency generated by a programmable interval timer within the processor subsystem. The filter output interfaces with a secondary filter stage and a sample and hold circuit time sychronizing all the 96 channels. The common problem associated with SCF is the realization of the reference frequency on the signal or filter output. The secondary filter is configured to elliminate or filter out this undesireable noise. A secondary problem of SCF is the introduction of voltage offsets on the order of 20mv. The sample and hold (S/H) is coupled with a potentiometer providing a means of elliminating the offset. The use of the substitute voltage throught the calibration path enables the offset to additionally be removed post experiment by software methods. Each of the twenty channel modules interconnect via a shared analog backplane, where common signals are accessed and interface with the timing an control module and processor subsystem. Within the subsystem a single timing and control module, as illustrated in figure #13 multiplexes the 40 signal conditioned channels and provides a dual A/D path, where the A/D output is directly interfaced into the CPU data bus. This module generates the timing and reference signals utilized by the signal conditioning modules and provides the interface to the processor subsystem.

TIMING, CONTROL, & CONVERSION MODULE

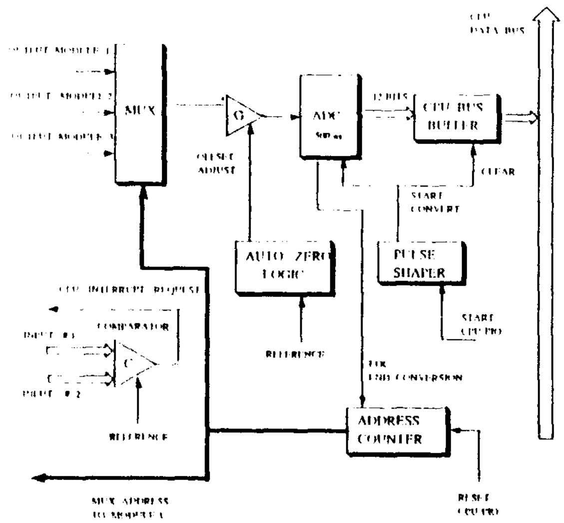


figure # 13

Processor Subsystem:

The processor subsystem provides the actual data acquisition, data storage and RS232 communications. The processor subsystem is based on an STD bus version of the IBM AT system operating at 16 MHz. The processor supports onboard RS232 capability, programmable interface timers (generation of sampling and filter reference frequencies), priority interrupt generators, and upto 4 Mbytes of dynamic RAM. One of the major problems with storing the data into CPU RAM memory, is that data offload is dependent on battery and processor subsystem survival. In order to resolve this dependence the system incorporates the use of the non-volatile solid state credit card memory subsystem as the main data storage media. The processor subsystem integrates via the STD bus to a solid state disk drive capable of real time storage of the dynamic data on the credit card memory devices. These devices statisfy the new industry memory standards and are currently produced in 2 Mbyte versions with 64 Mbytes versions to be available in the near future. This will enable a continuous upgrade of memory storage capability without modification to the current system design. The system no longer relies on data download to the supporting laptop computer, which typically required significant time, dependence on system battery life and processor integrity. The credit card memory device can be removed from the manikin following an experiment and simply plugged into a corresponding solid state disk drive on the IBM laptop. As a backup procedure, data is stored in parallel on the CPU RAM and is available for of download to the laptop via standard RS 232 methods.

Battery Assembly:

The battery assembly consists of multiple battery packs necessary to provide the voltages and power, to operate the DASS, and supporting transducers. The battery subsystem consists of rechargeable batteries distributed on the femur of the manikin. The battery voltages are regulated to provide the precise voltages required. Additiionally, the voltages are controlled by the processor subsystem via a series of relays and blocking diodes, enabling the processor to power manage the system maximizing battery life while minimizing battery requirements.

DASS Operating Software:

The DASS operating software is a combined "C" and assembly language application operating under the DOS operating software. This software is embedded on EEPROM within the manikin processor CPU module. The DASS software consists of multiple subroutines accessed from a main system monitor / communication interface software package. This system monitor communicates with the laptop exchanging *command codes defining the operations to be performed as specified by the user. The software enables the user to define the DASS sensor configuration, gain, sampling frequency, and filter cutoff. Additionally, the software provides multiple types of calibration (RCAL & Voltage Substitution), diagonostics, and data offload (backup). The primary function provides real time data acquisition and data storage. System data is stored on the non-volatile credit card memory removeable from the DASS system and directly transferable to an equivalent solid state disk on the IBM laptop for processingas detailed previously.*

Laptop Computer Support Station (User Interface)

The laptop computer is based on an IBM portable PC or compatible which provides the user interface and functions as the DASS controller. The PC is based on a 386-DX processor operating an DOS 3.3 operating system. The system application is written in "C" and provides a user friendly interface the DASS. The PC software communicates with the DASS processor via dedicated RS232 port (secondary backup port also available). A series of command codes are exchanged between the processors speicfying user commands, system acknowledgements and execution of the specified operations. The user interacts with a windows type of display interface where each selected option sends specifc command codes to the DASS commanding the software to execute specific operations. The user has the capability to configure and define the DASS uniquely for each experiment,(ie. sensor / channel definition, program specific channel gains, specify sampling frequency, filter cutoff and acquisition time).

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Improving Manikin Biofidelity

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1. SUMMARY

Two programs demonstrating the feasibility of improving the dynamic response of ejection system test manikins have been completed for the U.S. Air Force (References 1 and 2). The first program developed a manikin neck that has greater biofidelity during vertical impact conditions than currently available manikin necks. The second program developed manikin arms and legs with proper mass and mass moments of inertia to improve dynamic response. Both programs were conducted to support the development of the U.S. Air Force's Advanced Dynamic Anthropomorphic Manikin (ADAM).

The improved manikin neck specification was based on the properties and dynamic response characteristics of human necks. A neck mimicking these dynamic response characteristics was designed to interface with the ADAM and the Hybrid III and to withstand the severe environmental conditions imposed by ejections. The basic design approach incorporated a separate neck beam to control head translations, and head/torso straps to control head rotations. These neck components simulate the bone and muscle components in the human neck. The neck was fabricated and dynamically tested to demonstrate satisfactory strength and human-like motions.

Manikin limb segments were developed to achieve desired mass properties while maintaining the strength needed to withstand severe ejection forces. The Articulated Total Body (ATB) model program was used to predict joint design loads, and a finite element modeling program was used to analyze structural strength. Composite materials were used to fabricate the bone components; a unique polymer was used to fabricate the flesh. This combination improved the inertial property distribution by an average 30 percent over the current all-metallic ADAM limbs. A set of limbs was fabricated and statically tested.

These improvements will provide increased confidence in neck loading tests, especially with additional head-mounted equipment, during ejections and survivable aircraft crashes. The use of composites in segment construction will allow more realistic limb motions and impact energy absorption by the flesh material.

2. INTRODUCTION

Manikins have traditionally been used in the military to test ejection seats and the effectiveness of various crash protection designs. Emphasis in system testing has been on the operational effectiveness of the system to perform according to its design objectives. Primary concerns have been with inertial load effects on ejection seat acceleration and stability, and harness and fixed seat effectiveness in restraining occupants during survivable crashes. Assessment of human injury potential has been based on external body measurements and observations such as ejection seat acceleration (Reference 3), body interference with aircraft components or personal equipment, or failures in restraint, seat, or other protection systems.

More recently, with refinements in manikin design and advances in instrumentation capability, the trend has been toward the measurement of internal manikin responses and the use of these in making relative system safety assessments. The automotive industry has fully adopted this approach for frontal crash safety compliance testing in which Part 572 and Hybrid III dummies are used. A similar approach is currently being sought for side impact safety compliance testing with three candidate manikins having been developed; the SID, the EUROSID, and the BIOSID. Internal measurements are made in these dummies and results are compared, either directly or after having been used in specific algorithms, to determine injury likelihood.

The Air Force has developed the Advanced Dynamic Anthropomorphic Manikin (ADAM) (Reference 4) to test advanced ejection systems with vectored rocket thrust capabilities. The ADAM design accentuated human-like dynamic response to provide proper human body reactive loading into the ejection seat. This requirement led to an ADAM design that includes highly articulated joints with position sensing, a dynamic z-axis torso response, over 50 internal sensor channels, a self-contained data acquisition system, and durability to withstand ejections into a 600 Knot Equivalent Air Speed (KEAS) windstream. While a number of novel features were developed for the manikin, the substructure was a conventional steel design with foam-filled flesh coverings. This design met the specifications for segment and whole-body masses, but individual segment moment of inertias could not be matched well to human data because of the concentrated metal mass at the center of the segments and the necessity for a low-density flesh covering to provide proper segment mass. The ADAM also used a Hybrid III dummy neck with a modified Part 572 dummy head.

While the ADAM represents substantial improvement in ejection testing manikins, the use of a neck designed for frontal impact safety assessment and limbs with poor mass distribution and energy absorption properties led to two parallel efforts to improve these designs. The two efforts consisted of the development of a neck with proper z-axis (vertical) response as well as consistent x-axis (fore-aft) and y (lateral) responses; and the development of limb segments made with composite material substructures and a flesh covering with human-like energy absorption properties.

3. DISCUSSION

Two separate feasibility assessment programs were conducted to improve manikin biofidelity (References 1 and 2). The first program pertained to the development of a biofidelic manikin neck (patent pending). Until this program, the human neck response characteristics to vertical impact loads had not been completely evaluated. The objective of the Manikin Neck Development program was to design a neck with the capability to respond biofidelically to vertical loads as well as to forward and lateral loads. The second manikin improvement program pertained to the manikin arms and legs which, until recently, were designed with a heavy metal core encased by flexible, foam-filled molds. The core is substantially heavier than bone and the mold is considerably lighter than flesh. This construction results in mass distributions that differ from those of human segments, a structural rigidity that is much greater than that for bones, and an inability to absorb the desired amount of impact energy. The objective of the Manikin Limb Development program was to design arms and legs to have a mass distribution closely representing the mass distribution in human limbs.

4. MANIKIN NECK DEVELOPMENT

The method that was used to determine the feasibility of developing a manikin neck for ejection seat testing initially involved defining the desired neck response characteristics to vertical impact loads. The existing Hybrid III neck response characteristics were also examined to determine if the Hybrid III neck could be modified to produce desired response characteristics to vertical impact loads. After concluding that the Hybrid III neck could not be modified to respond correctly to vertical loading, several neck design concepts were generated. A Neck Concept Demonstrator was fabricated and tested to determine if the design concepts were valid. Modifications to the Neck Concept Demonstrator were made until the desired response was nearly achieved. A prototype neck was then designed to interface existing manikins and instrumentation. This prototype was fabricated and tested. The results of the prototype testing and Neck Concept Demonstrator tests were combined and used to develop the final neck design.

4.1 Design Method

The neck design method was determined by conducting three tasks. First, the desired neck response characteristics were defined. Second, the Hybrid III manikin neck design and response characteristics were examined to determine if the Hybrid III neck could be modified for vertical impact loading. Finally, neck design concepts were generated.

Define Desired Neck Response Characteristics. Both the kinematic and kinetic response characteristics of the human neck system were defined. Kinematic response characteristics are defined as the translations and rotations of the head/neck system with respect to time. Kinetic response characteristics are the forces and moments in the head/neck system. The latter characteristics were calculated from the kinematic response characteristics using known head and neck mass properties. If the manikin head has humanlike mass properties (i.e., total mass, proper center-of-gravity location, and mass moments of inertia), it follows that a neck system producing proper kinematic response characteristics will also have the proper kinetic response characteristics. Therefore, the kinematic response characteristics were used to define the manikin neck design criteria.

A large data base of human response testing, available from the Naval Biodynamics Laboratory (NBDL), was used to determine response criteria. The data base included human test results for impacts in the forward (-x), oblique (-x+y), lateral (+y), and vertical (+z) directions.

In the past, several researchers have reduced the NBDL test data to define kinematic and kinetic response requirements. However, sources could not be found which had reduced the test data for vertical impact directions. Vertical impacts were of particular interest to this development program since the intent was to develop a neck for ejection seat testing manikins.

3. Brinkley, J. W., "Acceleration Exposure Limits for

8. BIOGRAPHIES

The +z impact data included a total of 27 tests for four volunteers with nominal peak input accelerations from 5 to 12 G. Data reduction indicated that the kinematic and kinetic responses were somewhat sporadic. It was postulated that the variation in response was caused by active muscle action. Active muscle action could not be practically duplicated with a passive manikin neck. Thus, the kinetic response for each test was evaluated. Tests with a 'high' active response level were eliminated, leaving a total of 11 tests. These 11 tests included all four volunteers with input accelerations from 7 to 12 G.

The head angle and neck angle response corridors for the 11 selected tests are shown in Figure 1. The corridors are based on the calculated mean for all 11 tests, plus or minus one standard deviation. The head angle is defined as the change in global head angle. The neck angle is defined as the change in angle of a line between the first thoracic vertebra (T1) at the base of the neck and the head pivot point (occipital condyles) at the top of the neck.

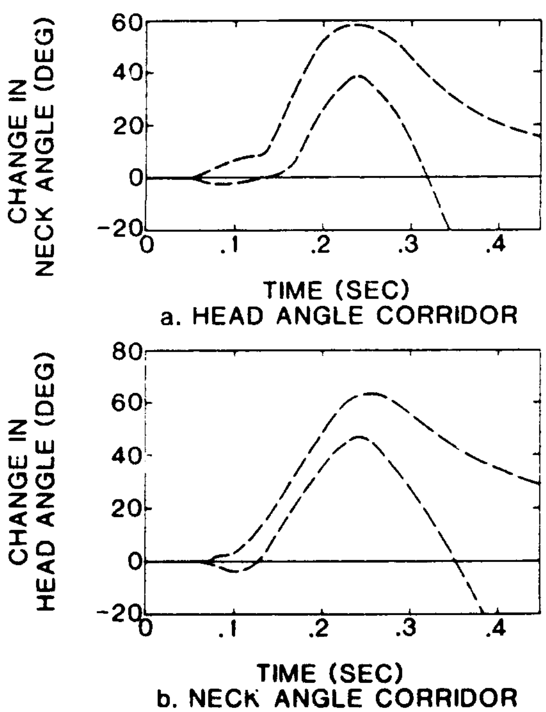


Figure 1.
Recommended head angle and neck angle response corridor for 7- to 12-G vertical impacts, passive neck system.

The average kinetic response at the occipital condyles (O.C.) was also calculated for the 11 selected tests. The moment was presented as a function of the change in head angle, and the forces as a function of time. The kinetic response for vertical impacts was compared to the response for forward impacts. For all practical purposes, the response for the two impact directions was the same. This conclusion indicated that a passive neck system could be designed to provide proper response to both vertical and forward impacts.

Examine Existing Manikin Design and Response Characteristics. Having defined the desired neck response directly from vertical impact load data of the human neck, the Hybrid III neck design and response characteristics were examined to determine if it could be modified to provide the desired response. The Hybrid III neck is depicted in Figure 2. The Hybrid III neck consists of an elastomeric neck beam with the base mounted at the approximate anatomical location of T1. The top of the neck pivots at the O.C. location and snubbers are placed between the top of the neck and base of the head.

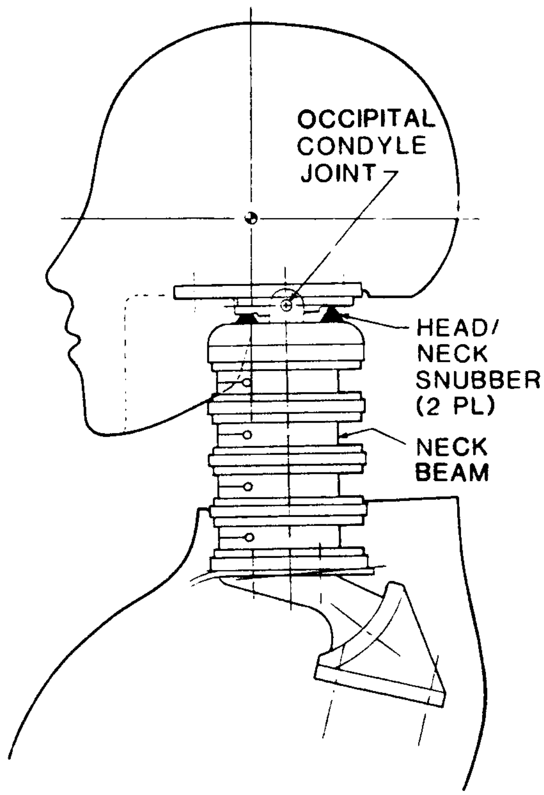
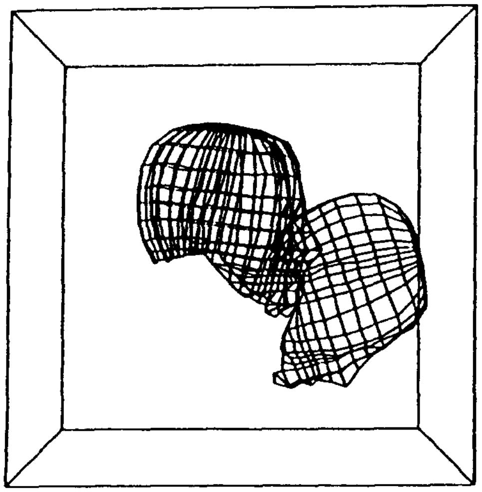


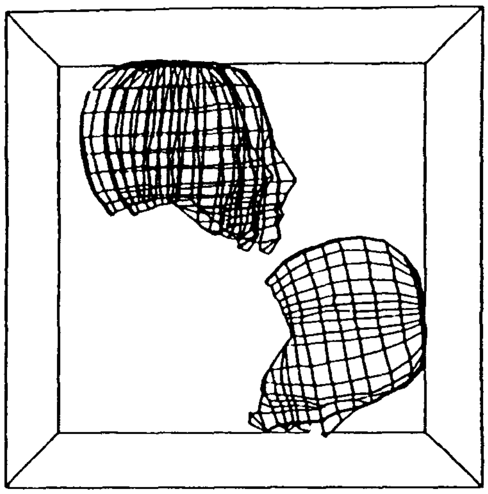
Figure 2.
Hybrid III neck.

Research on the Hybrid III neck indicated that it was designed to provide the proper head rotation and moment at the O.C. for forward and aft impacts.

Figures 3 and 4 compare the head trajectories of the Hybrid III and a typical human in response to 15-G forward and 12-G vertical impacts (Reference 5). For forward impacts, the maximum head angle is

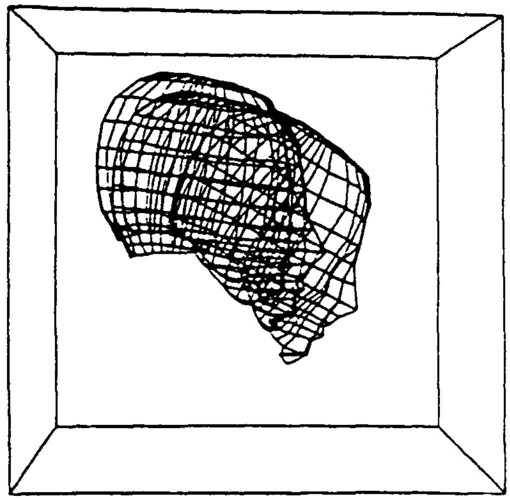


HYBRID III

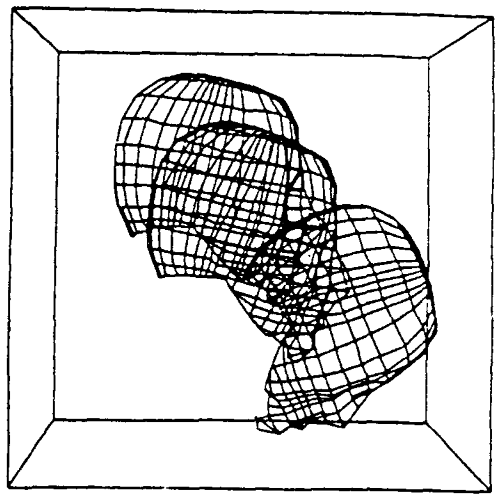


HUMAN

Figure 3.
Comparison of head trajectories for 15-G, forward impacts, NBDL Run Nos. LX5002 and LX3983 (Reference 5).



HYBRID III



HUMAN

Figure 4.
Comparison of head trajectories for 12-G, vertical impacts, NBDL Run Nos. LX4742 and LX4651 (Reference 5).

approximately the same for the Hybrid III and the human. However, the head forward and downward translation, or the neck angle, is much less for the Hybrid III than for the human. For vertical impacts, the deficiencies of the Hybrid III are even more pronounced. The results of these tests indicate that the Hybrid III neck beam is too stiff.

If the basic Hybrid III neck design was modified to produce the proper neck angles (head translation), then the head angles would be too high. This phenonmenon is illustrated in Figure 5 which shows a representation of the approximate head angle with the neck angle at 102 degrees (peak neck angle for a 15-G forward impact, Reference 6). The desired head angle for a 15-G forward impact is 78 degrees, significantly less than the observed head angle of 126 degrees in Figure 5.

Examination of the Hybrid III neck indicated that the head angle will always be greater than the angle of the top of the neck. Thus the Hybrid III neck cannot be modified to provide the proper response, and a new neck design was developed.

Identify Biofidelic Neck Design Criteria. The well-defined response of the human neck system was used to establish the design criteria for a biofidelic neck. The

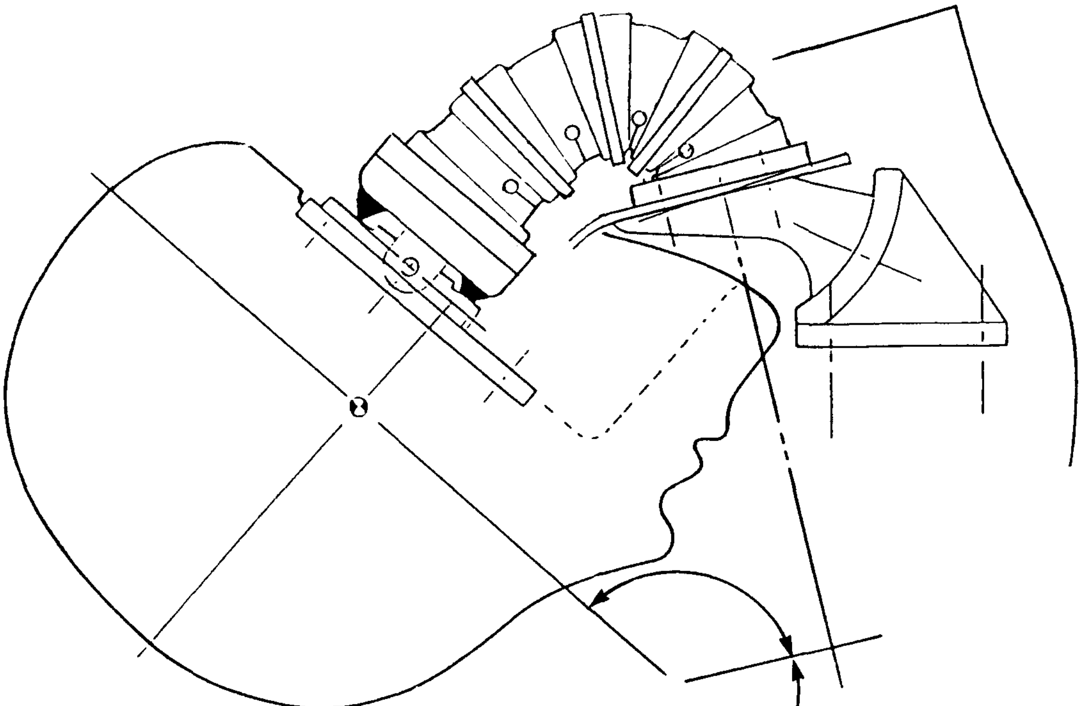


Figure 5.
Representation of peak head angle for a manikin neck based on the Hybrid III design adjusted for proper neck angle.

human kinetic response characteristics led to the observation that:

- A direct relationship exists between the moment exerted on the head at the occipital condyles and the relative change in head/torso angle, with the moment resisting forward head rotation.

- The neck structure exhibits ordinary elastic properties, with the moment generated at the base of the neck directly proportional to the change in neck/torso angle.

Several passive neck design concepts were generated in an attempt to produce these characteristics. In general, the concepts consisted of a neck beam that could be sized for proper neck angles, or head trajectories, and an independent method of controlling the moments exerted on the head. The most promising design consisted of an inner neck beam with a pivot point at the O.C., similar to the Hybrid III design. Instead of snubbers between the top of the neck beam and base of the head, straps were attached between the base of the head and the base of the neck. This design concept allowed the neck beam and the head-to-torso straps to be somewhat independently sized to provide proper head rotations and translations.

4.2 Neck Concept Demonstrator Fabrication
A neck system was fabricated to evaluate the developed concept. The fabricated head and neck assembly is shown in Figure 6. The neck was designed specifically to be easily fabricated and modified. The neck beam was fabricated from a stack of elastomeric 'washers' with an inner cable linking the base to the top. These washers could be easily substituted with washers of a different diameter or material to modify the bending properties. The head-to-torso straps were fabricated from a continuous length of elastomeric material.

Resistance to neck beam motion was provided through compression of the neck beam washers. Resistance to head rotation was provided through extension of the head/torso straps causing a moment on the head. This moment is relatively independent of the head/neck angle.

The test head was fabricated from mild steel plate and the ballast weights were sized to give a final instrumented head weight of 11.0 lb. The head c.g. was located 0.9 in. forward and 2.2 in. above the head pivot point. The measured moment of inertia of the head about the y-axis (pitch axis) was 110.3 lb/in.^{2}. The ballast weights could easily be moved to study the effects of change in c.g. location.

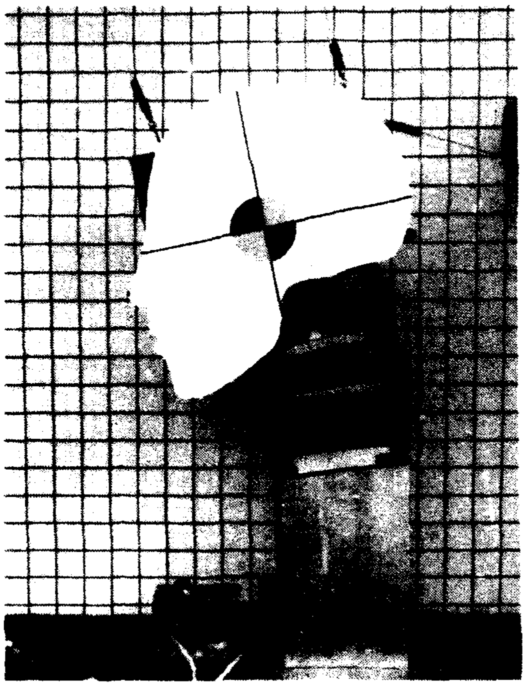


Figure 6.
Neck concept demonstrator (patent pending).

The neck assembly was attached to a test base which allowed for clearance between the head and test frame during maximum movement. The test base provided an initial neck angle of seven degrees pitched forward. The top of the neck beam tapered to allow proper clearance under high head/neck angles.

4.3 Neck Concept Demonstrator Testing

The neck system was tested for vertical as well as forward impacts. The testing showed that the response to vertical impacts was strongly dependent on the initial head/neck position and the c.g. location. However, the response to forward impacts was not strongly dependent on these variables. This condition explained the sporadic response of the human testing results for vertical impacts, and the more consistent response observed for forward impacts. The testing also showed that the neck beam and head/torso straps could be altered to change the neck and/or head angles.

Since the response to forward impacts was more consistent, and the human data base for forward impacts was larger, the forward impact testing results were used to size the neck beam and the head/torso straps. The response to vertical impacts was adjusted by shifting the center of gravity and/or changing the initial head/neck position.

The head and neck angle response of the final concept demonstrator design is shown in Figure 7. The calculated moment at the O.C., relative to change in head angle, is shown in Figure 8. Both results were very close to the desired nominals specified in Reference 6.

The neck system fulfilled the objectives by validating the proposed design concept. The overall dynamic response of the neck system was very good, with both the kinematic and kinetic responses comparing favorably with human test results.

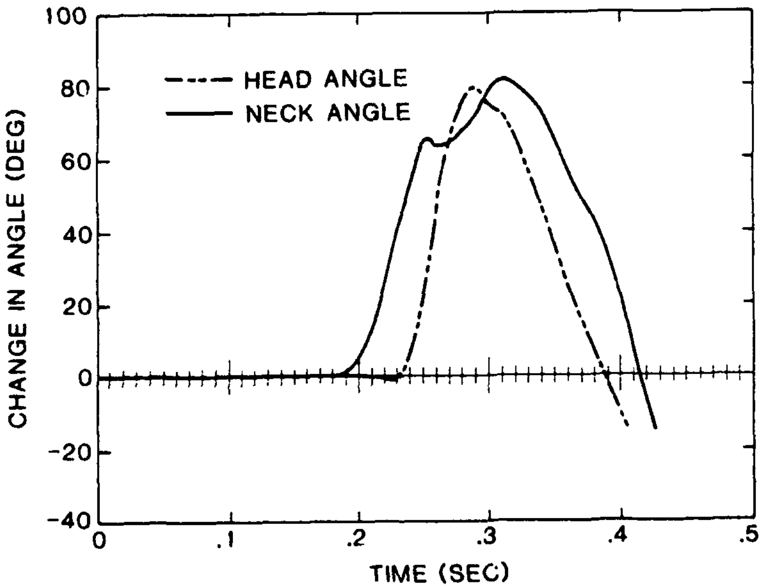


Figure 7.
Head and neck angle response, concept demonstrator design, 15-G forward impact.

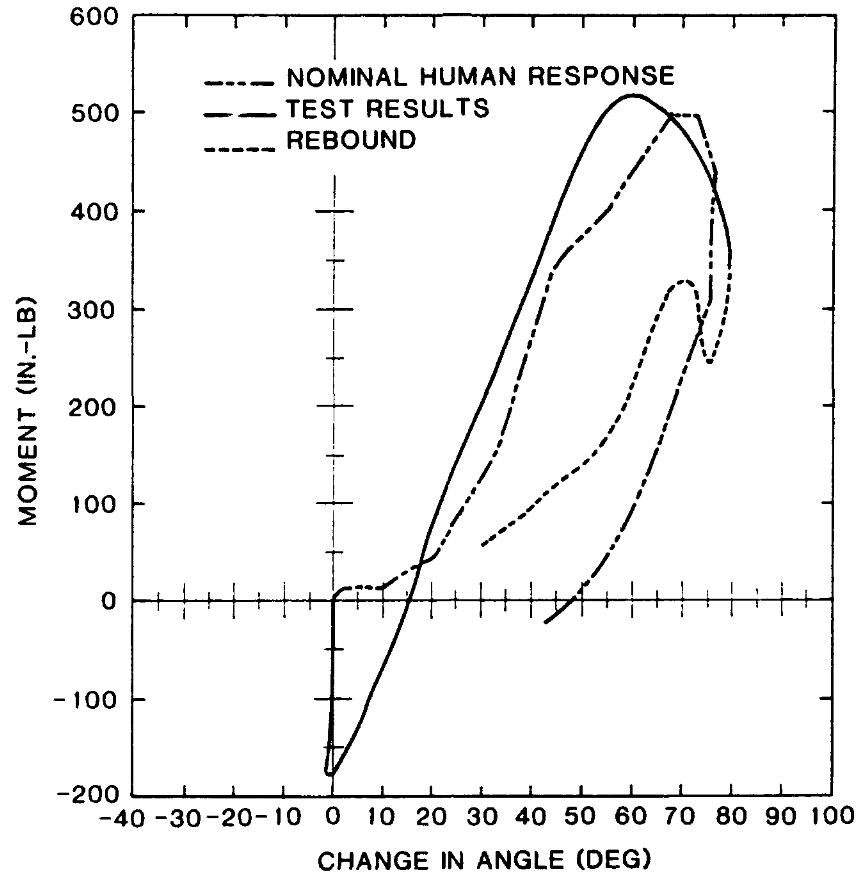


Figure 8.
Calculated moment at the occipital condyles relative to change in head angle, concept demonstrator design, 15-G forward impact.

4.4 Prototype Neck Design
The concept demonstrator was designed for proper flexion response to forward and vertical impacts; however, it was not designed specifically to interface with existing manikins. Therefore, a prototype neck was designed to interface with existing manikins as well as existing instrumentation, such as the head/neck load cell. The prototype neck was also designed to provide omnidirectional response.

Modifications were made to the concept demonstrator design to produce the prototype neck design characteristics. The modifications include the following:

- The stack of neck beam washers was replaced with a solid elastomeric beam. The center cable was maintained to ensure ruggedness.
- The head-to-torso straps were replaced with a cylinder between the neck base and the load cell interface plate.
- A torsion release joint was added at the top of the neck beam to provide the desired torsional stiffness (for lateral impacts).

4.5 Prototype Fabrication and Testing
The prototype neck system was fabricated and then subjected to a series of tests, including forward, vertical, and lateral impacts. The neck was modified throughout testing to improve performance. The prototype neck is shown in Figure 9.

The kinematic response of the initial neck design for a 12-G vertical impact is shown in Figure 10. The response was within the desired limits. However, the head angle was near the maximum limits and the neck angles were shifted toward the lower limits.

The kinematic response for the same neck tested at a 12-G forward impact is shown in Figure 11. The peak head angle was 100 degrees, which is higher than the desired nominal of 78 degrees. The peak neck angle was 92 degrees, near the desired nominal of 89 degrees for a 12-G forward impact.

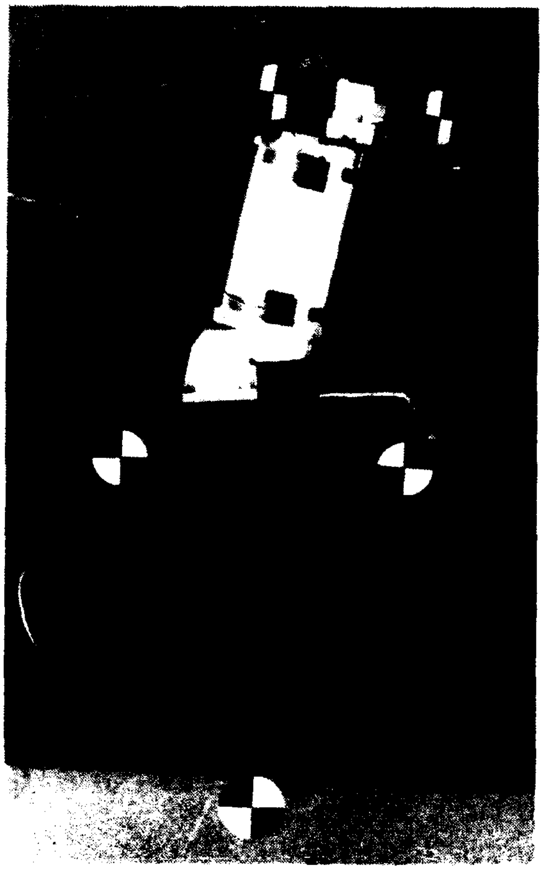


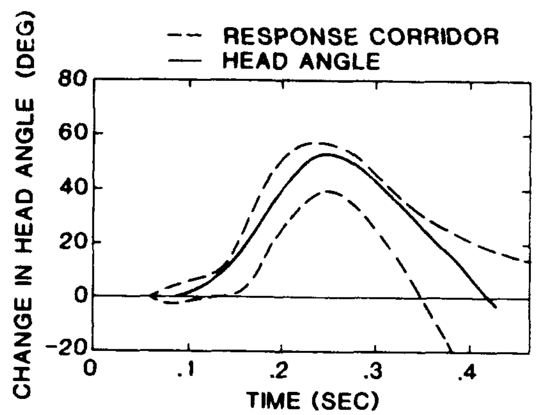
Figure 9.
Prototype neck (patent pending).

The test results to this point indicated that the neck inner beam stiffness was accurate, but the neck outer cylinder was not stiff enough to achieve the desired response.

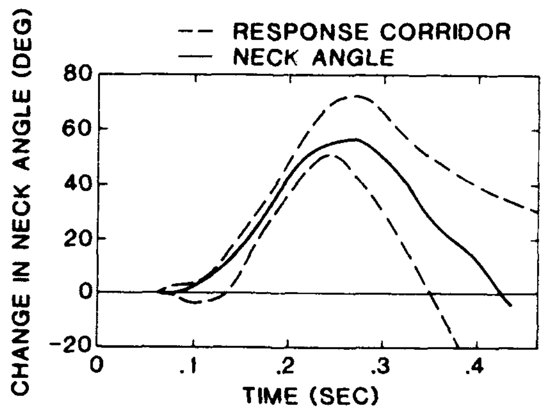
Prior to stiffening the neck outer cylinder, a series of lateral tests was conducted. The lateral tests showed that the neck structure was too weak. Thus, lateral stiffeners were added to the neck outer cylinder and tested until the correct lateral stiffness was identified.

Finally, the neck was retested for forward and vertical impacts. Surprisingly, the peak head angle increased and the peak neck angle decreased. It was expected that adding stiffeners to the neck outer cylinder would have decreased the peak head angle. Further attempts to refine the neck response did not produce the desired response for both lateral and forward impacts.

Further analysis and testing indicated that the neck outer cylinder could not produce the same response provided by the head-to-torso straps of the concept demonstrator design. The cylinder was behaving more like a beam than independent straps. As the neck deflected forward,



a) Head angle response



b) Neck angle response

Figure 10.
Head and neck angle responses for the prototype design compared to suggested response corridor, 12-G vertical impact.

the top of the cylinder also naturally rotated forward, behaving as a hollow beam structure.

4.6 Results

Enough information and test data were gathered at this point to design a neck system to combine the best characteristics of the concept demonstrator and the prototype. The final neck design consists of an inner core which functions like the neck beam from the previously described designs. The inner core provides the desired higher lateral stiffness without adding to the forward stiffness. Instead of stand-offs between the neck core and head-to-torso straps, elastic hinges are integrally molded with the neck system. The aft head-to-torso strap is larger in cross section than the forward strap to provide the proper response for flexion as well as extension.

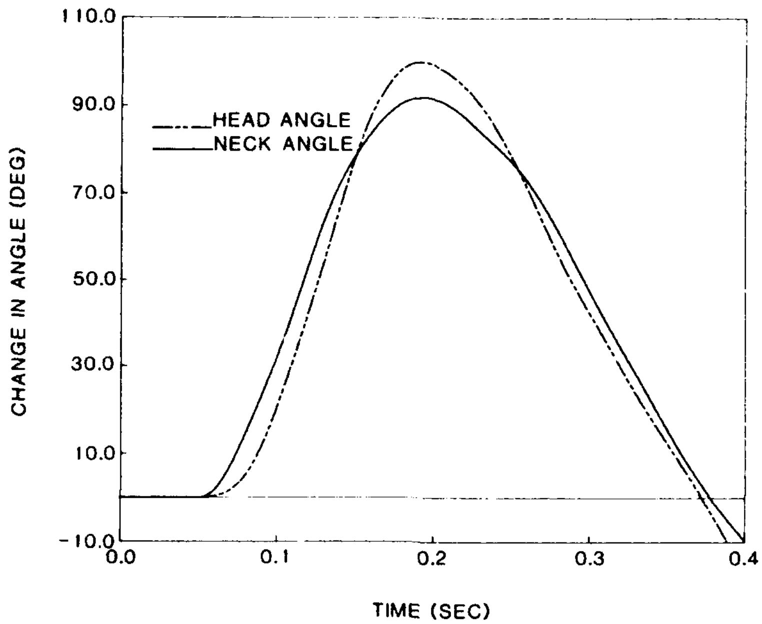


Figure 11.
Head and neck angle responses, prototype test no. 9, 12-G forward impact.

The final neck design has not been fabricated or tested to date. However, all testing and computer modeling results indicate that this final design should produce the desired results.

4.7 Conclusions

This program demonstrated the feasibility of developing a biofidelic manikin neck: a neck that will respond as a human's would when subjected to both vertical and horizontal impacts, as well as to lateral impacts. In particular, the program demonstrated that a passive neck can be designed to produce biofidelic response.

The program concluded that a biofidelic manikin neck design should have the provisions that allow head translations and rotations to be independently controlled. The neck designs of currently produced manikins do not have these provisions. Primarily, a biofidelic manikin neck should be designed with a neck beam sized for proper head translations and head-to-torso straps sized for proper head rotations.

5. MANIKIN LIMB DEVELOPMENT

This development effort determined the feasibility of using composite materials to optimize the mass moment of inertia properties in manikin upper and lower arm and leg segments while maintaining the strength required for ejection seat testing into a 600 KEAS windblast. The small ADAM was used to achieve this feasibility study. The program consisted of designing, fabricating, and testing the limb skeletal structure as well as designing and fabricating an upper leg flesh component.

5.1 Design Method

The design method theoretically established component configuration, material construction, and composite layup to achieve desired mass distribution and strength properties of each limb component. This method consisted of several tasks. First, design goals were established by identifying the inertial properties of human limbs and evaluating the design of the ADAM. Second, the joint design loads were predicted using the Articulated Total Body (ATB) model program by subjecting the occupant model to severe dynamic loading conditions. Third, a computer-aided design (CAD) program was used to obtain the desired inertial properties for each component. Finally, a stress analysis was conducted to evaluate the strength of the designed limb components when subjected to the design loads predicted by the ATB model. Critical composite limb components were fabricated and tested to verify component strength.

The flowchart in Figure 12 illustrates the sequence that was used to design the skeletal limbs. A separate task was established to design the flesh component.

Select Design Parameters. The design parameters that were identified include mass properties of the 3rd-percentile male limbs, geometry of the existing ADAM limb components, and human flesh characteristics.

The weight and inertial properties of the 3rd-percentile (small) male were identified for each manikin limb segment. Inertial and geometric properties were obtained from a Tri-Services Report (Reference 7) and were used to specify the segment mass and mass moments of inertia

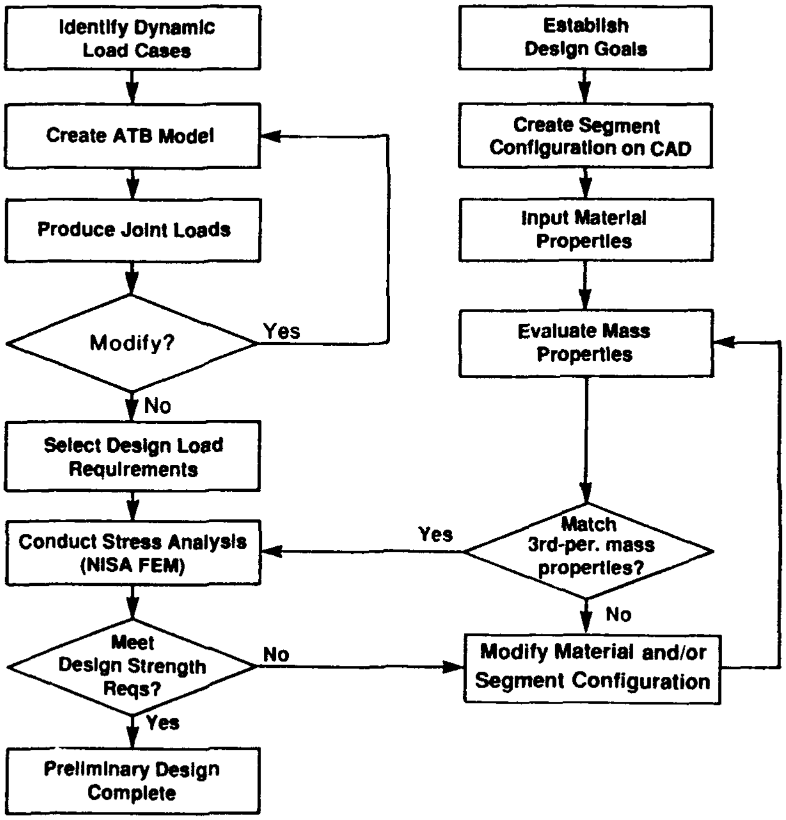
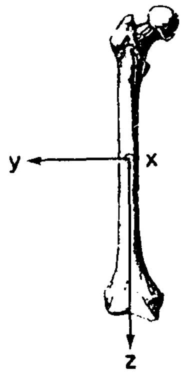


Figure 12.
Design process.

Table 1.
Segment mass properties design requirements

Component	I_{xx} (in.-lb-sec^2)	I_{yy} (in.-lb-sec^2)	I_{zz} (in.-lb-sec^2)	Weight (lb)
Upper leg	.941	.993	.256	17.1
Lower leg	.357	.362	.042	6.8
Upper arm	.074	.077	.015	3.4
Lower arm	.053	.054	.008	2.5



for the upper and lower arms and legs. Table 1 lists the design weight for 3rd-percentile male limbs. The desired mass moments of inertia about the x, y, and z axes for each limb are also listed in Table 1.

The geometry of each ADAM limb component was also determined. The components of the ADAM arms and legs are shown in Figure 13. An extensive literature search and some in-house testing were conducted to identify the characteristics of human flesh. Desired flesh properties defined for the manikin include: density (0.034 lb/in.^{3}), hardness (Shore A Durometer 13.1), and dynamic impact load (approx. 125 lb when impacted with a 0.65-lb mass dropped from a height of 24 in.). Materials demonstrating these characteristics were identified. Material availability and processing ease were also considered during the final selection process.

Determine Design Loads. The Air Force ATB modeling program was used to predict the manikin design loads. A 3rd-percentile male occupant was modeled and positioned in an ACES II ejection seat model. This seat/occupant system was subjected to 11 different loading cases typical for an ejection. These loading cases were represented by half-sine pulses and include: forward sled pulse (+Gx, 45 G max at 120 msec), aftward sled pulse

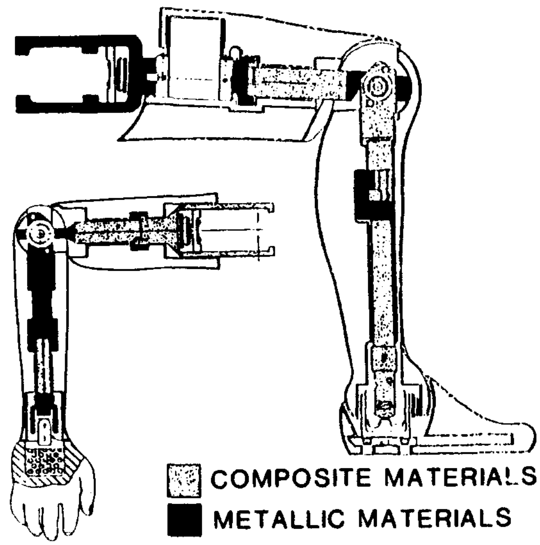


Figure 13
ADAM arm and leg components.

(-Gx, 45 G max at 120 msec), side impact pulse with and without seat armrests (+Gy/-Gy, 45 G max at 120 msec), upward and downward ejection pulse (+Gz/-Gz, 45 G at 120 msec), windblast alone (600 KEAS constant), and combined windblast with upward and downward ejection pulses (+Gz/-Gz, 45 G max at 120 msec and 600 KEAS constant).

The occupant motion and the loads at each limb joint were calculated and evaluated. An example of the occupant motion during a constant 600 KEAS windblast force is shown by a series of illustrations in Figure 14. Figure 15 presents the torques about each axis in the shoulder and elbow joints during the same loading condition (600 KEAS windblast). The worst-case load combinations (forces and torques) for each joint were identified by examining all the loading conditions. These worst-case loads occurred during the windblast-alone loading condition, and the lateral condition without the armrests. These loads were used as the design loads for the corresponding manikin limb components (Table 2).

Develop Segment Design. ANVIL 5000, a CAD software package, was used to design the manikin components. This software package was used to iterate between component configuration and material selection to achieve the desired mass properties for each complete segment. Each complete segment consisted of the skeletal and flesh components combined to achieve the correct inertial properties. First, the existing ADAM limb configurations were input to the CAD and used as the design baseline. These baseline configurations were then modified and combined with selected material properties to achieve the desired weights and mass moments of inertia for the segments. The process was an iterative one as segment geometries were modified and/or materials were changed to achieve the desired properties.

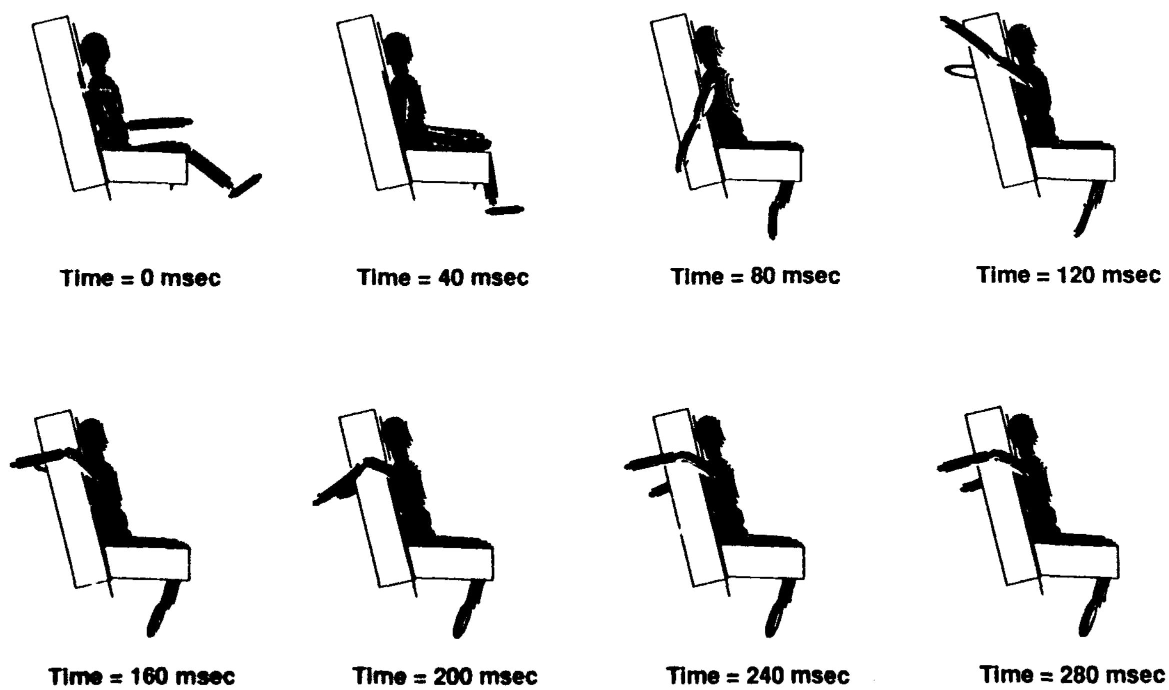
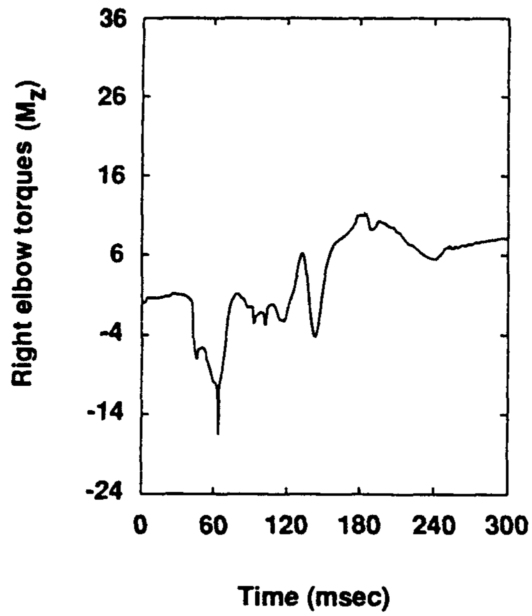


Figure 14.
Example ATB occupant motions, 600 KEAS windblast.



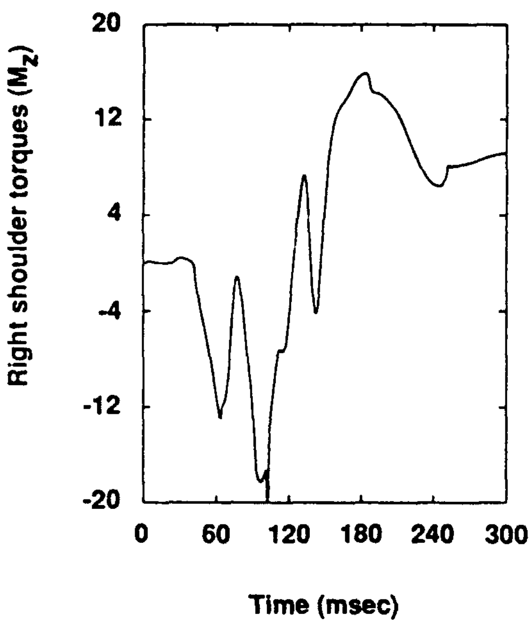


Figure 15.
Example ATB right upper arm joints torque time-histories: 600 KEAS windblast.

Conduct Stress Analysis. The NISA II Finite Element Model was used to conduct a stress analysis on each limb segment (Figure 16). The completed designs of each segment, as defined by the CAD, were directly transferred to the NISA program. The design loads predicted by the ATB Model program were applied to the appropriate segments. The fabric layup sequence for each of the composite components was determined at this stage. This step played a critical role in developing a design that met all of the strength requirements of the component.

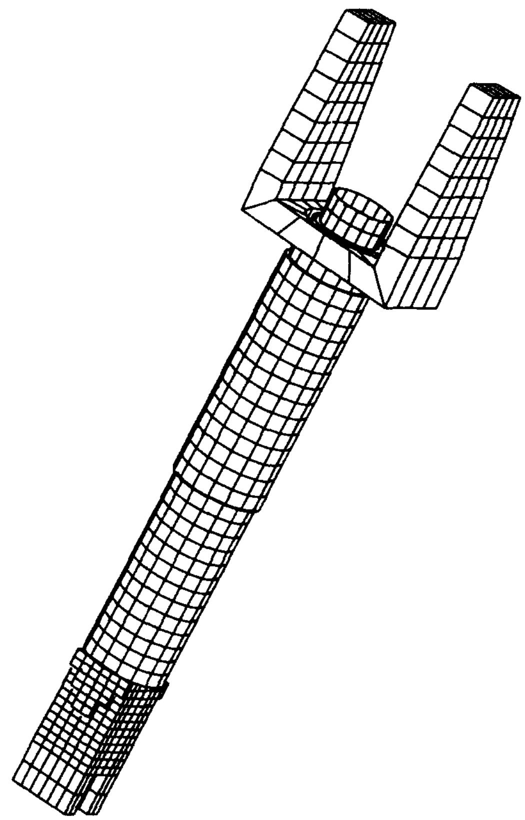


Figure 16.
Finite element model of upper leg segment.

The stress distribution of complete limb segments (i.e., upper arm segment, lower arm segment, etc.) was analyzed along with stress concentrations at clevis pin joint holes and joint stops. When the analysis indicated that a component did not exhibit the desired strength properties, modifications to the component were conducted either by rearranging the ply orientation or by modifying the configuration or material selection. The modified CAD component was then again directly transferred to the NISA program and the stress distribution was redetermined and analyzed. This process was repeated where necessary until all of the components withstood the desired design loads, and exhibited the desired weight and inertial properties.

5.2 Skeletal Limb Fabrication

All the composite components were fabricated using a unique layup design of graphite/epoxy plies for each component. Each tubular bone component was fabricated by wrapping graphite prepreg tape around a tubular mandrel that was appropriately sized for each particular limb. Fiberglass/epoxy corrosion barriers were laminated to metallic-interfacing surfaces. The ends of bone segments that required additional strength were tapered with graphite hoop wraps. Where two graphite components are designed to rotate about each other, a

Table 2.
Design loads

Segment	Dynamic* Load Case No.	F_x(lb)	F_y(lb)	F_z(lb)	M_x(in.-lb)	M_y(in.-lb)	M_z(in.-lb)
Upper Leg	3	180	-500	-200	15,000	2,000	1,500
Lower Leg	5	-1,480	50	-2,780	-1,300	-19,500	0
Upper Arm	5	-1,280	580	-140	500	140	-1,720
Lower Arm	5	180	140	-40	-1,580	3,000	0

* 3 - Lateral without armrests
5 - Windblast alone

Teflon®-impregnated fiberglass layer was laminated to the bone surface.

The composite shoulder, knee, and ankle clevises were fabricated on aluminum male mandrels. Wrapping tape around a male mandrel is ideal for fabricating intricate components such as these clevises because the tape can be aligned without causing any discontinuities in the reinforcing tape fibers. An inner foam core structure was incorporated into the shoulder clevis fabrication process to maintain the desired mass

properties in the clevis as well as to withstand the high stresses imposed on the clevis. Fiberglass/epoxy corrosion barriers were also laminated onto the appropriate surfaces of these clevises.

Shrink tubing was used in most cases to remove surface wrinkles caused by the vacuum bagging process. All composite layups were consolidated and cured in an autoclave with heat and pressure.

The hip, upper leg knee, and elbow clevises were all machined from appropriate metals. These clevises and the composite components were assembled into two complete limbs: the arm and the leg (Figures 17 and 18).

5.3 Flesh Component Fabrication

A dense, two-part polymer that solidifies at room temperature into a pliable, yet durable, material was selected for the upper leg flesh component. Hook-and-pile fastening tape was used to secure the opening slit in the flesh component. Additionally, the abutting surfaces of the slit were contoured to provide a self-locking joint. A scrim material was embedded in the flesh component near the surface to provide additional durability and tear resistance to the surface. The final configuration of the upper leg flesh component has an outer contour identical to the current ADAM upper leg since the same mold was used. The inner configuration of the flesh component was modified to fit the composite upper leg skeleton.

5.4 Testing

Static testing was conducted to evaluate the strength of the manikin skeletal components. The upper leg, lower leg, upper arm, and lower arm segments were each individually tested. Static loads were applied to the joints of each segment representing the three components of forces and moments that developed at the joint during the limb's severest dynamic loading conditions as calculated by the ATB program.

5.5 Results

The results of this program are summarized in Table 3, Table 4, and Figure 19. Table 3 lists the components for each limb segment and the material that was selected for each segment to achieve the desired mass properties. Figure 19 compares the inertial properties of the lower leg segment designed in this program with the existing ADAM limb segments and the 3rd-percentile male design goal. The results illustrate that the mass properties of the modified segments much more closely represent those of the 3rd-percentile human than do the ADAM segments.

This outcome demonstrates the potential for the ADAM, adapted with the modified segments, to respond with more human-like kinematics when subjected to dynamic load conditions. Table 4 lists the actual skeletal segment weights combined with the calculated flesh cover design weights. These weights are compared with the 3rd-percentile male total segment design goal weights.

5.6 Conclusions

This program has demonstrated the technical feasibility of using composite structural components in advanced manikins. The program results have shown that human-like, total segment inertial properties can be achieved; sufficient durability to withstand violent testing

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Figure 17.
Arm assembly prototype.

Figure 18.
Leg assembly prototype.

Table 3.
Material selection

Segment	Upper Clevis	Insert	Tube	Lower Clevis	Stops
Upper Leg	Titanium	Aluminum	Graphite/Epoxy	Stainless Steel	Aluminum
Lower Leg	Graphite/Epoxy	Aluminum	Graphite/Epoxy	Graphite/Epoxy	Aluminum
Upper Arm	Graphite/Epoxy	Aluminum	Graphite/Epoxy	Aluminum	Aluminum
Lower Arm	Titanium	Aluminum	Graphite/Epoxy	Aluminum	Aluminum

Table 4.
Segment weight comparison

Segment	Actual Weight (lb)	Calculated Weight (CAD) (lb)	Design Weight Goal (3rd-Percentile Male) (lb)
ARM			
Upper Skeletal	1.34	1.22	
Lower Skeletal	0.80	0.80	
Joint Hardware	0.22	0.22	
Upper Flesh Cover	2.07*	2.07	
Lower Flesh Cover	1.64*	1.64	
Total Arm Weight	6.07	5.95	5.90
LEG			
Upper Skeletal	7.77	8.07	
Lower Skeletal	1.85	1.54	
Joint Hardware	0.26	0.26	
Batteries	1.59*	1.59	
Upper Flesh Cover	7.02	7.09	
Lower Flesh Cover	5.26*	5.26	
Total Leg	23.75	23.81	23.90

*Calculated using computer-aided design (CAD).

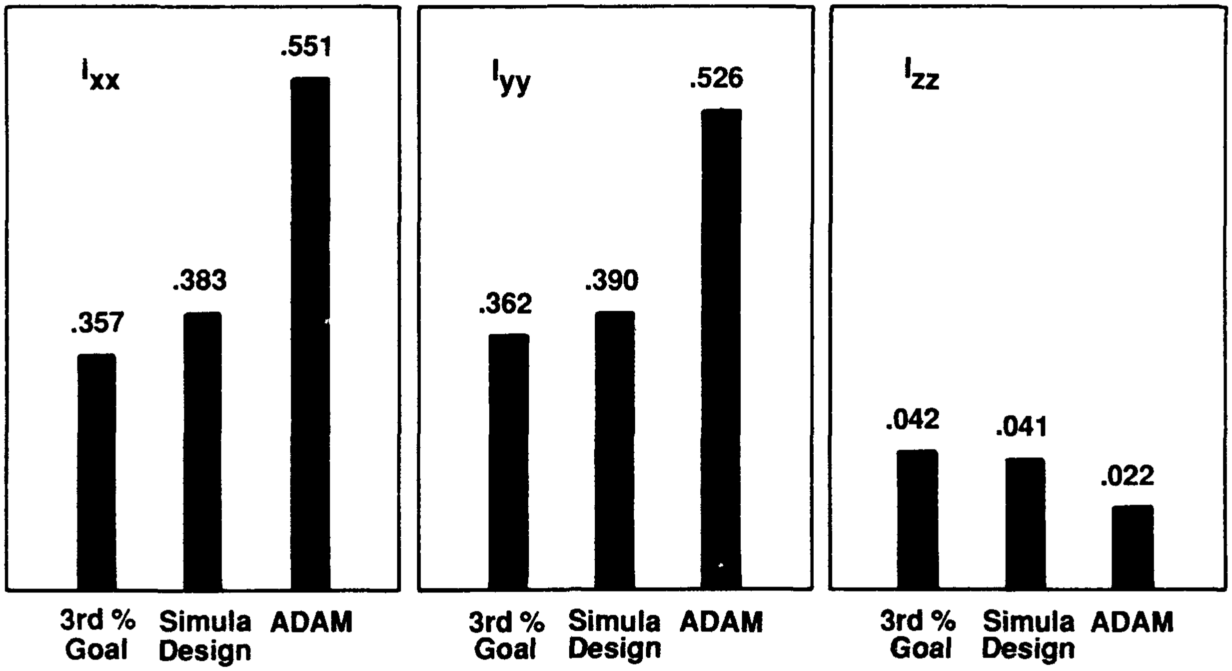

Figure 19.
Lower leg mass properties comparison.

conditions can be met; surface molds that possess flesh-like energy-absorbing properties can be used; and that mechanical designs allowing proper joint articulation and resistive properties, as well as measurement of joint motions, are viable.

Composite materials were used to redesign the ADAM limb segments, achieving mass properties that are more representative of the human while maintaining the strength required for the manikin to survive the ejection seat test environment. The mass in the segments was redistributed by reducing the weight of the skeletal components, and by increasing the weight of the flesh components. Graphite/epoxy unidirectional prepreg tape was the composite material used to fabricate the bone segments and a dense polymer was used to represent the human flesh.

6. RECOMMENDATIONS

These two manikin developments, the neck and the composite limbs, represent significant advances in manikin technology for military testing applications. The neck development provides the first z-axis response testing capability and has current application in the investigation of added head mass effects on neck loading. The composite segment development can be expected to improve gross motion simulations, but, perhaps more importantly, it will allow the use of flesh molds that absorb energy in a manner similar to that of human flesh. Both of these developments improve the biofidelity of manikins, can be applied to manikins other than the ADAM, and bring closer the ability to use internal manikin measurements for injury likelihood assessments in aerospace environments.

The next steps in this process are to implement the neck design, perform validation tests on the neck, and develop response-injury correlations. With respect to composite limb development, full manikin impact testing should be performed to establish a degree of improvement due to more human-like segment mass distribution. This testing could be conducted on a single manikin equipped with original limb segments on one side and composite limb segments on the other side. The flesh response should also be investigated by conducting impact tests on a manikin equipped completely with composite limbs and flesh. The energy absorption characteristics for this manikin would be measured and compared to that of the human and current manikins.

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THE DESIGN AND USE OF AUTOMOTIVE CRASH TEST DUMMIES

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SUMMARY

Anthropomorphic crash test dummies have been used by the automotive industry for many years in order to develop safer road transport. Accident investigations have shown how vehicle design has improved, with the number and severity of road casualty injuries decreasing despite increased use of road transport. Several different types of dummy of differing levels of sophistication are used to approve vehicles to a number of different standards and regulations. Dummies are used either to approve restraint systems at the component level or in full vehicle impact tests. Various performance criteria must be met by anthropomorphic test dummies, and these criteria are discussed with reference to the interests of the vehicle designer, the biomechanical engineer and the legislative authority.

The paper concentrates on the approach to dummy design used to develop the new European Side Impact Dummy EUROSID-1. The methodology used to develop certification techniques is described as well as the dummy itself. Techniques to calibrate a dummy in terms of predicting human injury risk are reviewed. The techniques described are common to all automotive crash test dummies and can be applied to the design and development of anthropomorphic dummies to be used in other disciplines.

1. INTRODUCTION

Road transportation has and continues to be a major source of human injury and as such is a drain on the resources of any country. In the UK in 1951, when statistics became available, a vehicle population of 4.7m units existed associated with 178,000 personal injury accidents. In 1990 the vehicle population had risen to 24.7m motor vehicles and there were 258,000 personal injury accidents.[1] Although the overall number of accidents has increased by over 40% over this period the number of vehicles has increased by over 400%. Examining the data in more depth shows that the number of pedestrians and motorcyclists killed, the most vulnerable groups, have fallen by 30% and 40% respectively but other forms of transport, mainly cars, has risen by over 200%. These figures do not necessarily indicate that other transport modes have become safer but that there has been a large movement away from motorcycle and pedestrian transport. Examining the proportion of accidents resulting in death and serious injury shows that the proportion of car occupant causalities suffering fatal injuries has fallen by 15% and those suffering serious injury by 30%. The reduction in fatal and serious injury proportions is attributable to a number of factors, one of which is the use of advanced crash test dummies to develop safety systems. In a financial perspective the cost of road accidents in the UK in 1990 was estimated to be £6,700m of which £5,300m was attributed to personal injury accidents. Statistics clearly indicate that road transport is costly, both in financial and human suffering terms. Many improvements are still possible, to reduce further the cost of human misery.[2]

Several different approaches are used to reduce both the number of accidents and the severity of any personal injury. Vehicle safety is frequently divided into two areas called 'primary' or 'secondary' safety. Primary safety is concerned with the prevention of an accident occurring whilst secondary safety is concerned with reducing injury risk once an accident has occurred. Primary safety therefore deals with road design, junction layout, driver education and also vehicle handling and braking performance. Secondary safety concerns the vehicle itself, its impact performance, its ability to absorb impact energy in an accident and the performance of any occupant restraint system, the aim of which is to reduce the risk and severity of traumatic injury to the vehicle occupants. To some extent secondary safety can also relate to the design of the vehicle's exterior with respect to impacts against pedestrians. Crash test dummies are frequently, although not exclusively, used to evaluate secondary safety features both inside and outside of the vehicle. They can be used either to determine injury risk or simply to load a surface or restraint system up to a realistic level in a semi-realistic way. Being a human surrogate they have to exhibit several human-like characteristics and, depending upon usage, how well they simulate a human can vary.

Figure 1 European Side Impact Dummy, EUROSID-1.

This paper initially reviews the use of crash test dummies within the automotive industry examining how and when they are used. The necessary attributes of any test dummy are examined as well as the design process. The development of the thorax of the European Side Impact Dummy EUROSID-1, Figure 1, is reviewed as an example of this process. The importance of dummy certification to defined performance requirements (Section 3.4) and dummy calibration against human tolerance levels (Section 4) is developed within the paper. The design and development of crash test dummies is not unique to the automotive field and many of the procedures reviewed in the paper can equally be applied to the development of other anthropomorphic dummies, in other disciplines.

2. AUTOMOTIVE CRASH TEST DUMMIES

Crash test dummies perform two basic tasks in vehicle safety. The first is to load the vehicle or safety system dynamically and requires a fairly simple dummy, while the second is to indicate the type and severity of any injury that a human might sustain in the impact, which requires a much more complex dummy. Not all complex dummies, used to study injury risk, are able to be used in the same impact situation. This is clearly seen in the frontal and side impact conditions. In a frontal impact, in which the occupant is restrained, the mechanisms of injury are likely to be deceleration based, with occasional occupant to interior surface contact, whereas in a side impact the occupant on the struck side of the vehicle will be directly struck by the intruding structure of the vehicle. With the different injury producing mechanisms and load paths in side impacts it is essential to have a dummy capable of correctly representing a human in these different impact environments and able to detect the potential injury mechanisms.

Dummies can be used to represent several different types of road user. Three attributes, size, directionality and complexity are determined by each dummy's basic role. Not all testing with dummies is centred on full scale crash testing with whole vehicles. In addition to being able to study vehicle and restraint interaction effects it is important to be able to approve and study the performance of restraint systems in a simpler and less costly way.

In general complex dummies are designed to be able to detect loads likely to cause skeletal fractures, deceleration injury to internal organs and, in some cases, laceration injury. They are used in research and biomechanically based legislative test procedures. Simple dummies are used to quality assure components in legislative test procedures.

Not all safety assessment tests are carried out using complete dummies. Simpler, much less complex tests, are performed with 'impactors' representing individual human body parts, to evaluate interior surfaces or components. One such impactor is a rigid hemi-spherical impactor representing the head, evaluating interior surfaces.[3] Another headform is used to approve crash helmets in a simple drop test onto an anvil.[4]

2.1 Adult Dummies.

The most obvious use of crash test dummies is inside cars being crash tested, in 'legislation directed' impact testing. There are two types of whole vehicle legislative test, frontal impact[5] and side impact[6] using sophisticated dummies.

2.1.1 Frontal Impact Dummies.

In frontal 'whole vehicle' testing two complex US dummies are frequently used, the Hybrid II and its development into Hybrid III. The Hybrid II dummy was initially developed to study the injury risk of unrestrained occupants and the safety of air bags. The principal UK and European restraint system is the lap and diagonal seat belt. Neither of the US dummies has a good human-like shoulder and thoracic structure for quality evaluation of belt restraint systems. A more human-like dummy the OPAT[7] was developed in the UK, and is used by the TRL, to study the performance of 'belt' based restraint systems. OPAT has not become an 'internationally recognised' dummy for legislative testing. To be better able to evaluate belt based systems more reliably in addition to airbag restraints, NHTSA in conjunction with the European Experimental Vehicle Committee (EEVC) is currently developing a new advanced frontal dummy thorax called ATD50.[8]

A very early dummy still in use at TRL as a 'make weight' dummy in general impacts, is a dummy developed by the Royal Aircraft Establishment in the 1950s[9] for parachute harness testing. A modern version of this dummy is the Rescue Dummy developed for use by the emergency services in the UK.*

For general quality assurance applications simple low cost dummies are used, in which no instrumentation may be needed. Impact testing on crash test sleds is used to assess and improve the safety of 'sub-systems' like seat belts, an example of which is the approval, within Europe, of adult seat belts to ECE Regulation 16.[10] This test uses a less complex dummy than those used in full scale vehicle impact testing, as the dummy's main function is to 'load' the restraint for 'strength' testing rather than to evaluate injury mechanisms and injury risk. The TNO10 dummy,[11] used in this regulatory test, is a very simple, one legged dummy with little biofidelity and minimal instrumentation capability.

2.1.2 Side Impact Dummies.

Side impact loading conditions are very different from the frontal ones. Three special side impact dummies are currently available to study side impact injury risk. Only the DoT-SID is specified for use in a current legislative test procedure.[5] The DoT-SID dummy has the capability of measuring injury risk in the thoracic area only, whereas the other two dummies, BIOSID[12] and EUROSID-1,[13] can assess injury risk in the head, thorax, abdomen and pelvic areas. An Advanced Notice of Proposed Rule Making within the US indicates that the current side impact standard might be reviewed to allow the use of one or both of these more advanced dummies.[14] Within Europe a new side impact directive has been discussed, using the EUROSID-1 dummy, with an enactment date of 1995.[15]

2.1.3 Pedestrian Dummies.

Pedestrian injury has fallen dramatically in the UK over the years. This is not necessarily a result of improved vehicle design but more a result of changing travel patterns, transport systems, road design etc. To improve further the situation for pedestrians struck by cars, safety research is carried out on the exterior of cars using special dummies. These are often modified 'in vehicle' dummies, the principal modifications being to the pelvis and to the legs giving the lower limbs a higher degree of biofidelity and injury measuring capability.[16] The pedestrian version of the OPAT dummy is used by TRL. Its legs have been redesigned to measure both leg impact accelerations and leg bending forces. For legislative purposes component tests using impactors are being developed, based on the results of impacts using these dummies.

A simple pedestrian dummy for assessing the safety of vehicles was developed in Sweden and France, having only a single leg,

* 'The Emergency Rescue Dummy' is a product manufactured by OGLE Design Ltd, Letchworth, Herts. UK.

to improve test repeatability in a possible legislative procedure.[17]

2.1.4 Motorcycle dummies.

As for pedestrians, motorcycle injury has fallen dramatically due to reduced numbers of motorcyclists and changed usage of motorcycles. Again improvements are possible and tests are now being carried out on motor cycles in order to reduce the high risk of lower limb injuries to motor ··clists. For this type of impact seated dummies with special load measuring legs are used to study and develop leg protection systems and other advanced protection systems such as motorcycle air bags.[18]

One dummy modified for use in motorcycle testing has been developed in Canada and is a derivative of the Hybrid III frontal dummy.[19] Another motorcycle dummy is based on the OPAT dummy and has been used extensively in the UK at TRL.[18]-[20] The UK dummy legs are covered in an aluminium honeycomb material, enabling post crash assessment of impact energy to be made.

2.2 Child Dummies.

All the previous discussion has related to dummies based on the adult population. Children change rapidly in shape, mass and physical structure especially in the earlier years. Although conventional adult restraints can protect children from excessive injury, special child restraints, designed for a particular size category, can improve the protection levels afforded to children. Within Europe and the UK special child sized dummies are used to develop and approve child safety devices.[21] [22] The main European dummies are produced in the Netherlands and the UK and are based on five child sizes. The dummies represent the 50th percentile mass child for an 'at birth' baby (called P0), a 9 month old child (P3/4), 3 year old (P3), 6 year old (P6) and 10 year old (P10).* Since the main role of the dummies is the 'approval' of child safety systems, they are fairly simple. The dummies were designed with appropriate dimensions and mass distributions to load child restraints dynamically, and also to detect potentially injurious circumstances deriving from high chest acceleration and abdominal loading resulting from submarining. There is basic instrumentation in the abdomen and thorax but a high degree of biofidelity is not one of their prime features.

3 AUTOMOTIVE DUMMY DESIGN.

3.1 Requirements.

A test dummy is designed to be a human surrogate in a crash test. As with many test devices the design and development is a compromise between a number of conflicting requirements. The following paragraphs detail the principal design attributes of a dummy. Depending upon eventual dummy usage the relative importance of each attribute will be different.

3.1.1 Anthropometry.

One of the prime functions of a crash test dummy is that it should have similar shape, mass distribution and joint articulations to that of the human. Base anthropometric data is fairly easy to obtain except for segmental masses, segment moments of inertia and segment centres of gravity. The most recent data on motor vehicle occupants has been generated in the USA.[23] The previous data base used was also based on the US population.[24]

Adult dummies representing three size groups are defined. The most frequently used crash test dummy is the 50th percentile adult male, representing 'Mr Average'. Two further dummies representing the ends of the adult population are occasionally used. One is a dummy representing the larger occupant, the 95th percentile adult male, and one for the smaller adult, the 5th percentile adult female. The precise size of a dummy is a compromise between several different requirements. Based purely on a collection of average segment linear dimensions and segment masses a dummy would not equate to the average human. This problem is even more pronounced if the 5th and 95th percentile is considered. In order to produce a given percentile dummy principal dimensions are selected, and from these compromises are made to produce the overall dummy. For car occupants the stature is obtained by combining seated height and leg length, other dimensions, such as shoulder width, chest circumference etc, are selected to suit.

Child dummies are defined by age and are intended to represent the 50th percentile child for that age.

3.1.2 Biofidelity.

Biofidelity is the degree to which a surrogate duplicates the properties of the living subject which it is intended to represent. As far as automotive dummies are concerned, it usually applies to the dynamic response to impact conditions. A test dummy must have an acceptable level of biofidelity in order to respond in an impact in the same way as a living human would. The acceptable degree of biofidelity is dependent upon the ever .al use of the dummy. A high level of biofidelity is necessary in order to study injury risk. This is the most difficult of all the design attributes of a crash test dummy for two main reasons. Firstly, the scarcity of good, relevant biofidelity design data and secondly the assessment of whether the measured biofidelity of the developed dummy is sufficient. Since the biofidelity of a dummy is required for injury risk assessment in an injury producing environment, the design data must also be available for this same environment. Some limited human volunteer data are available at low energy sub-injury producing levels, but obviously not at high energy injury producing levels. Most high energy data are obtained from cadaver testing, originating in the USA, Germany and France.

Cadaver tests can be split into two main types, full body impacts and discrete body region impacts. The latter type of test can be further split into two types, discrete tests performed on a complete cadaver and those performed on dissected body parts.

The value of the cadaver data, for the purposes of defining the performance of an automotive test dummy, is highly correlated to the type of impact being performed and the parameters being assessed. Cadavers cannot exhibit many of the attributes of the living body. Care must be taken in evaluating the biofidelity of a dummy based purely on cadaveric responses. To some extent the value of the cadaver data itself is dependent on the condition of the cadaver at the time of the impact test, whether fresh or embalmed, and the condition of the donor at time of death - age, nourishment and cause of death etc. Cadavers do not have any muscle tone nor any natural internal body pressure from circulatory systems, both of which can have a strong influence on responses to impact. Cadaveric tests used to determine the kinematic performance of the neck will be of limited use since the cadaver is not able to support its ow.. neck pre-impact or control

* The European child dummies are distributed by TNO, Delft, Netherlands.

Figure 7.
Head and neck angle response, concept demonstrator design, 15-G forward impact.

its articulation and displacement during an impact, whereas an impact to the skull studying skeletal fracture thresholds would have more relevance. Impacts to the thorax are less clearly defined since the performance of the thorax is a combination of skeletal strength, pressure, muscle tone and visceral components, the proportionate influence of each being difficult to determine. Test environment is also likely to have a strong influence on the response of a cadaver. Gravitational effects can influence the mass distribution and shape of the cadaver compared to a live subject.

Considering these many influences the cadaver data must be critically reviewed and prioritised.

3.1.3 Repeatability.

A test dummy, like any other item of test equipment, must give the same output when subjected to the same input. This dummy attribute is slightly at variance with respect to the response of a human in that the same human might respond differently due to muscle tone or respiratory condition to the same input.

A vehicle impact test can have many possible variations, so dummy repeatability is usually quantified in well controlled 'non-vehicle' impact tests. An assessment of dummy repeatability can be gained by examining peak dummy responses from repeated tests with the same dummy. Where a test has been repeated more than once the Coefficient of Variation(%), can be derived from the mean response value and the standard deviation. The greater the number of repeat tests the better is the quality of the estimate of the Coefficient. It is generally considered that a Coefficient of Variation of about 10% is acceptable for complex crash test dummies, under well controlled test conditions.

3.1.4 Reproducibility.

Reproducibility is very similar to repeatability but is the extension of repeatability to other identical dummies. Different dummies built to the same design must give the same results from a similar impact. To assess reproducibility several samples of the same dummy should be tested at the same establishment in order to eliminate any additional variation present between test establishments. To assure reproducibility dummies are subjected to a range of certification tests. (See Section 3.4)

3.1.5 Robustness.

Robustness is a deviation from the human characteristic. Whereas a human could be injured in an impact and become structurally 'unsound', the dummy is usually required to remain structurally intact. In order to improve vehicle design the dummy must be able to record the extent of any overload rather than the knowledge that an overload had occurred in excess of the dummy's strength. Knowing the amplitude of overload enables a counter-measure of known response to be developed. Dummy robustness is an important aspect in terms of vehicle development costs.

Robustness as defined above is not always required with in all dummies, since dummies with frangible elements are used for specific purposes. Frangibility has been suggested to investigate the effect of breaking legs on the 'free flight trajectory' of a motorcycle dummy,[19] though frangible components have the disadvantage that they can give no indication of the extent of overload and the materials used may also introduce an undesirable variability.[25]

3.1.6 Sensitivity.

It is important that the test dummy is sensitive to impact but relatively insensitive to extraneous parameters like temperature and humidity effects. A dummy's response must vary in a reliable manner. Where an input varies in such a way that injury risk will change so must the dummy's output change. Conversely when evaluating the performance of a car it is not desirable that small differences in impact location on the dummy, which would not substantially change the risk of injury in a human, should produce large variations in dummy output.

3.1.7 Economy.

Crash testing can be viewed as a development overhead, thus it is desirable to minimise the cost of testing. Several of the attributes already discussed bear on the cost of maintaining the dummy in usable order. One of the other cost elements in crash testing is the initial capital cost of the dummy itself. The cost element also covers the expenditure necessary on instrumentation and data processing as well as the complexity and frequency of dummy certification.

3.2 Instrumentation.

The standard instrumentation and complexity of instrumentation in any dummy is a function of its ability to detect, and predict accurately, injury risk.

Two approaches to dummy transducer design can be taken. Firstly a continuously measuring device, giving a varying output for a range of inputs. Secondly a go / no-go type of measuring device eg. a switch[26] or a failing element like a frangible face form.[27] Of the two design philosophies the former method is the most frequently adopted and accepted in the automotive industry.

Most dummy heads are currently instrumented with three axes of linear acceleration. However arrays of nine accelerometers are now being used to study not only linear acceleration but also rotational acceleration of the head. Acceleration of the thorax and pelvis is commonly measured. Thoracic deformation is now being recorded in side impact and frontal dummies. Forces are measured in the abdomen and pelvis of the EUROSID-1 dummy. Many new specialised transducers have been developed to measure shear and bending forces as well as tensile and compressive forces, for dummy parts such as the neck and lumbar. A new instrumentation system is currently under development to study chest deformation and loading. The chest band is a strain gauged belt[28] that is strapped around the thorax and can measure deformation profiles dynamically. A current version of the chest band uses 42 data channels.

The second type of transducer, go / no-go devices, cannot address the problem of 'By how much did it fail?' Although switch type devices can be readily calibrated, frangible devices cannot, since 'failure' is their sense mechanism. Calibration of a frangible device is a contentious issue. Frangible devices can only be certified by quality assured production methods and by sample batch testing. Even so confidence in their performance is low since there is always the doubt whether 'a good sample' was used in the test. Retrospective testing of frangible elements that have not broken can take place but again uncertainty underlies retrospective certification since the sample could have been damaged during the impact.

3.3 Dummy Design Methodology

The most important design feature in any dummy is the desired level of biofidelity. Simple dummies used for quality assurance tasks are mainly design based, requiring little if any dynamic performance attributes. Dummies requiring a high degree of biofidelity must be certified and designed on a performance basis, as well as a design basis.

The design of any advanced crash test dummy is ... nly based on a two part specification. The dummy must first meet certain dimensional criteria (mass, shape and joint articulation). Secondly the dummy must conform to certain kinematic criteria. The first part of the specification is fairly easily met being based on easily measured parameters. The achievement of adequate kinematic biofidelity performance is a much more difficult problem, even after basic performance data on the dynamic performance of a human have been obtained.

As has already been stated crash test dummies are used to study high energy crash environments, in which human severe traumatic injury or death is a possibility in a human. Since live subject testing is not possible data based on human cadavers is used, with compensations being made to 'humanise' the cadaveric responses where necessary to make them more closely relate to the performance of a live human being. In addition since not all cadavers are of the same size and shape 'normalisation' of cadaver responses is carried out to 'correct' the data to a mean cadaver response. For a side impact dummy an ISO working group developed a set of design targets.[29] The EEVC re-examined the cadaver data and extended the ISO work to develop a more closely defined set of design targets for a side impact dummy. The EEVC also rated the requirements with respect to their appropriateness for defining the performance of a side impact dummy used to represent occupants in a vehicle impact, in terms of test repeatability, reproducibility and level of injury severity.[30]

Several different design methodologies exist to develop a crash test dummy. One very poor design process is to design, build a mechanical surrogate and then to develop it during a large programme of ad hoc impact testing, until a reasonable match exists between desired and actual performance. Although this is a valid developmental method, little can be learnt about the full dynamic performance of the dummy, other than the information gathered from whatever instrumentation may be used. A more broadly based and better method is to commence development with mathematical modelling of the human in the impact conditions in which the cadavers were tested and in which the dummy will eventually tested, the mathematical model being set up in the general form of how the final dummy might be built. This methodology allows the designer to obtain a better understanding of not only the cadaver test but also the planned dummy's performance in terms of stress/stiffness levels and any potential injury related indices. This latter design method was adopted by TRL for the design of the thorax of EUROSID-1. Figure 2 and Figure 3 show the developed computer model of the EUROSID-1 rib module and the rib design developed by TRL.

A lumped mass computer model of a thorax was developed by Langdon,[31] utilising the ACSL simulation language. Using this model sensitivity checks were made to determine the role of each of the individual elements of the thorax. The model was exercised against the three available cadaver data bases, impactor, sled and free fall drop tests, in more than two hundred simulations.

During the computer modelling period it was found that no single data set for the model could be used to match all of the three cadaver data bases. The conclusion was that either the three test

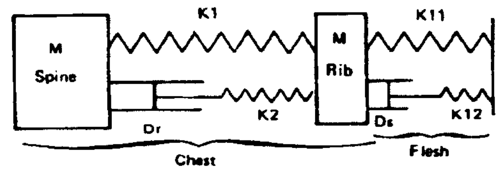

Figure 2 Computer model of EUROSID rib.

procedures were incompatible, or that the lumped mass model itself was over simplified. It was acknowledged that the thorax was modelled as a collection lumped masses, whereas the human thorax is mainly distributed mass around a low mass skeleton. Hand in hand with the modelling exercise preliminary rib units were manufactured and tested, the results being compared to the computer model predictions and to the cadaver data. The final mechanical design of the thorax was based on the cadaver data set that was considered to be closest to the car impact severity.

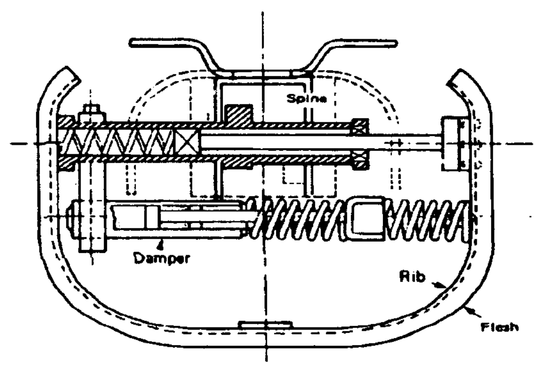

Figure 3 EUROSID-1 Rib Module

One of the cadaver data bases used was based on simple pendulum impactor tests. This test was also performed on a single rib module, rigidly mounted, thus permitting simultaneous development of the simulation model and of the rib. When the module was considered to be sufficiently well developed a full thorax was built of identical modules and evaluated against all of the three sets of impact tests, replicating the cadaver tests.

3.4 Dummy Certification.

Dummy certification is an element of both dummy repeatability and reproducibility. In order that all dummies built to the same design will exhibit the same dynamic performance each must be checked against a defined common standard, on a regular basis. Certification, sometimes loosely called calibration, is the process of checking, and component tuning, against a specified standard for that particular dummy. Automotive dummy certification is based on procedures at either full dummy or component level. Certification procedures need not necessarily be based on cadaver test procedures but should be based on a test at a level of severity similar to that in which the dummy will eventually be used. Automotive dummies are certified in pendulum, impactor and free fall drop tests as well as in quasi-static test procedures. All three techniques are used in the certification procedures defined for the EUROSID-1 dummy.[32]

4 DUMMY CALIBRATION AGAINST INJURY CRITERIA.

The calibration of a dummy is the derivation of the relationship between the transducer outputs and the risk of real human injury in an impact of similar severity. This relationship does not necessarily have to be a simple single parameter relationship but can be a complex combination of several measured parameters e.g. displacement and velocity. Once a relationship has been established between this criteria a 'level of acceptable injury risk' must be established, in order to create pass / fail levels for use in standards or regulations. It is also valuable for research purposes so that changes or improvements can be quantified in terms of reduction in injury risk.

4.1 Calibration Philosophies.

Actual dummy calibration can be achieved by a number of methods. One method is based on discrete cadaver impact testing, similar to that used to develop performance data for the dummy design. In this method direct comparisons are made between the cadaveric injury and dummy output. This approach is a valid one for initial calibration estimates, and the derivation of appropriate criteria. It has the disadvantage in that the calibration is based on a cadaver, which is not always a good representation of a living human.

A second calibration method compares dummy transducer data against real world accidents in which live occupants may or may not have been injured. Two techniques are used to make this comparison. The first is based on the reconstruction of selected accidents with a dummy representing the injured occupant in the accident. Much information can be learnt about the selected accident but whether the selected accident and injured/uninjured occupant is a good representative of the population at risk is an unknown factor. This can be a very costly and resource consuming approach to dummy calibration.

A potentially more accurate method is based upon a statistical approach to the analysis of a large sample of actual accidents with subsequent comparative impact testing. This approach is the most difficult of the two 'live subject' techniques as it relies upon having a large in-depth accident data base of adequate quality. Detail is needed on accident circumstances, vehicle damage and the injured and uninjured occupants. The way in which the accident data may be sampled can have a major influence upon the outcome of the calibration. Consequently it is important to sample accidents on an accident severity (input) basis rather than on injury (outcome) basis. For this calibration technique to be useful, data are required not only on injured occupants but also uninjured occupants in accidents of a similar severity. Data are also required on uninjured occupants in low severity accidents in order to regress fully across the injury and impact severity spectrum. This technique is possibly the best calibration method as it attempts to minimise the selectivity of the former approach. This statistical approach has been successfully used to calibrate a UK frontal impact dummy OPAT.[33]

4.2 Tolerance Criteria.

The selection of tolerance criteria is a function of the expected loading mechanism as well as the expected injury. If a body part is to be directly impacted, possibly with a concentrated force, it is inappropriate to measure only global acceleration as this could not adequately monitor the severity of the localised impact. The localised impact might cause a puncture injury, skeletal fracture or soft tissue injury. Body part accelerations might be expected to correlate better with internal organ damage rather than surface injury or fracture.

If a single injury criterion is adopted for a body part, the assumption is made that all potential injury to that body area is solely related to that one parameter. In reality injury can be caused by multiple factors. Failure of all biological material is known to be load rate dependent. Thus one could sustain minimal injury under slow crush conditions but sustain massive injury under high velocity crush conditions, for the same level of peak crush. Bone is a visco-elastic material[34] [35] and its properties are affected by the rate of deformation. A number of studies have demonstrated the relationship between injury and a viscous injury criteria[36] [37] while Langdon[38] suggests from a theoretical study of the thorax that a viscous based criterion correlates with shear strain in the soft tissues of the thorax.

A simplistic approach to tolerance levels assumes that below some threshold level injury never occurs and that above this level injury will always occur. This is very far from the truth. Injury severity and injury risk can vary due to several factors, including age, mass and sex and the physical condition of the occupant. The true relationship between impact severity and injury risk is of the form of a sigmoid curve as shown with associated confidence limits in Figure 4. For an increasing severity of impact the risk of injury increases, but not as a linear function.

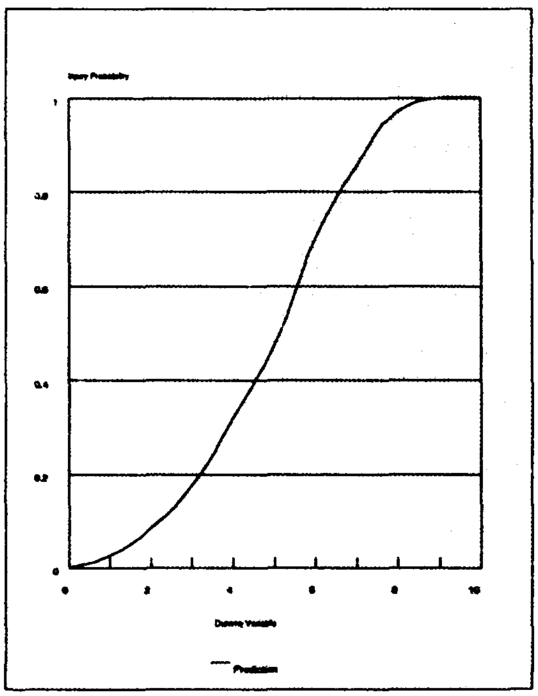

Figure 4 Probability of injury as a function of impact severity.

Obtaining this type of relationship from accident and dummy data uses a dose-response analytical technique called Probit analysis.[39] An alternative similar method uses the Logit transformation. The quality of this predicted relationship is shown in the confidence limits. Vehicle legislators must decide, when setting threshold limits, what is an acceptable level of injury severity and injury risk and on this assessment a pass/fail level can be set.

Threshold limits are set to reduce the threat to life and the occurrence of serious injury. The emphasis in the automotive industry is to reduce both fatal and serious injury as classified by the Abbreviated Injury Scale.[40] i.e. injuries ≥AIS3.

5 FUTURE USE AND DEVELOPMENT OF TEST DUMMIES.

5.1 Conventional Dummy Design.

Existing dummies have been shown to be useful test devices for improving safety systems in vehicles. More advanced test dummies are being developed along with more complex instrumentation systems. These new dummies will more readily differentiate between poor and better safety systems and, with enhanced instrumentation, will be able to evaluate injury mechanisms not now studied. In order to improve harmonisation across continents the EEVC is linking in with the development of the new NHTSA dummy programme [8] with the newly formed Working Group 12.

Most existing dummies are constructed from steel, or other metal, elements with conventional mechanical joints or links. This method of construction is poor, since there is a great difference between the density of steel and the density of the human skeleton it represents, thus the mass distribution within the dummy is poor compared to humans. To reduce the impact stiffness of the pelvis in EUROSID-1 a plastic pelvis has been developed. In addition EUROSID-1 incorporates advanced foam materials for use as flesh substitutes. It is expected that as a result of the quest for improved dummy biofidelity future dummies will need to be built using advanced 'plastic' materials, although this may make the dummies more temperature sensitive.

5.2 Mathematical dummies.

There exist several different computer modelling codes, and some of these contain a form of crash test dummy model. One of the many codes widely used in the automotive industry is MADYMO.[41] In this code, data sets for both frontal and side impact dummies exist. Many vehicle manufactures use more complex codes to help them develop safer vehicles, in greater detail. One such technique uses dynamic finite element modelling, as in, DYNA 3D.[42] These finite element models require very powerful computers on which to run. Vehicle manufactures develop finite element mathematical models in order to study vehicle collapse modes. Vehicles, though, are finally evaluated not on collapse modes but on injury risk as assessed by a test dummy. TRL in collaboration with Ford (UK) and Ove Arup are developing a detailed finite element model of the EUROSID-1 dummy. This collaborative research project, of which phase one is due to be completed during 1992, aims to bridge the gap between the structural collapse vehicle model and a full injury risk model.

6 CONCLUSIONS.

1.The design and level of dummy complexity is dependent upon eventual use.

2.Both simple and complex dummies have valuable roles to play in research and legislation aimed at reducing injury risk to all vehicle occupants involved in high energy, injury producing situations.

3.The approach to dummy design is not exclusive to the automotive industry and the use of automotive based dummies in alternative transport systems could show a benefit to humans in these other risk environments.

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AN IMPROVED ANTHROPOMETRIC TEST DEVICE

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ABSTRACT

This paper reviews recent experience with a new test dummy intended principally for use in motorcycle crash testing. Modifications to the Hybrid III to better service this particular environment also makes the device potentially suitable in aircraft occupant crash protection assessment.

This new ATD contains a 16-channel on-board data acquisition system, lower extremities that are capable of monitoring for leg and knee injuries, a more flexible lumbar spine, a penetration monitoring abdomen, a deformable thorax with improved motion sensing capability and a neck with improved flexion and extension bending response.

The femur and tibial complex are constructed of frangible elements whose biomechanical responses are based on available cadaver data. The knee is designed with fusible links that fail at load levels commensurate with that of human knee ligaments.

The test device has been used in full-scale crash tests as well as limited laboratory validation tests. This paper illustrates the potential of this injury monitoring device for aerospace applications as well as identifying areas of future work.

INTRODUCTION

Crash testing similar to that used for road vehicles is becoming increasingly important in the improvement of the crash-worthiness of aircraft. A car crash test occurs in a relatively controlled environment with little dummy motion occurring. The needs of this type of testing have led to the development of anthropometric test devices (ATD's) specifically designed for this environment in terms of impact response. As an example, the standard car crash dummy, the Hybrid III has three areas that can claim to human-like impact response; the head, the chest and the knees, and these have all been designed for impacts from the front.

This paper describes the modifications required to give a Hybrid III adequate levels of impact response and injury sensing capability for the motorcycle test environment. The crash environment of the motorcyclist and the aircraft occupant is very different from that of a car occupant. These crash environments are relatively unconstrained and of long duration in comparison to a car crash. A series of individual impacts may be of significance in assessing the overall injury potential of the crash. For this reason, the motion of the motorcyclist ATD must be as unimpeded as possible and it must be able to respond to a wider variety of possible injuries. Such a motorcyclist ATD has potential for injury monitoring in the aerospace crash environment as well. A modified version of the Hybrid III is already used for this type of testing [1]. The attributes required of a motorcycle ATD make it more suitable than the Hybrid III for both ejection seat testing and for studying the causation of injuries to aircraft occupants in crashes. For example, statistics for U.S. army aircraft [2] indicate that the four most common areas of the body to suffer fatal and major injuries in crashes are the head (20%), lower extremities (11%), vertebra (16%), and thorax (13%). In all these body areas, the motorcyclist ATD described here has these injury sensing capabilities.

In 1989, St-Laurent et al. [3], described the design and basic features of the first motorcyclist anthropometric test device, the MATD1. This ATD was based on a pedestrian style Hybrid III modified to be more suitable for motorcycle testing. The modifications were in three areas, to improve the injury sensing potential, to improve biofidelity and to include an onboard data acquisition system.

The most significant injury monitoring modification was to the lower extremities of the dummy. The standard steel femur and tibias of the Hybrid III were replaced with frangible units whose strength and stiffness characteristics mimicked that of the human. In addition, the knee complex was redesigned to allow simulation of ligament rupture at the appropriate biomechanical levels. The MATD1 also had additional modifications to the head and neck region to allow helmet fitting and hands which were able to grip the motorcycle handle bars. It was fitted with an on-board data acquisition system which filled the chest cavity of the dummy.

The MATD1 has been used in a crash test series [4]. Based on this experience, a further series of refinements to the ATD have been developed and this new version, known as the MATD2 is described herein. Changes to the on-board data acquisition system have allowed the thorax to retain the biofidelity of the Hybrid III thorax. This has been combined with more comprehensive chest deformation sensing capability. An injury monitoring abdomen has been added, along with a lumbar spine of greater biofidelity. Finally, a modified neck with improved kinematics in frontal impacts has been developed.

MATD DESIGN REFINEMENTS

Lower Extremities

The purpose of the modifications to the Hybrid III lower limbs was two fold. Firstly, the frangible units provide a direct means to assess various significant lower extremity injuries. The design is such that the frangible elements monitor for fractures at all points on their length and circumference, while the knee design provides direct evidence of the knee injury failure mechanisms. Secondly, it provides a more appropriate load path, and hence subsequent kinematics, in those cases when the crash would indeed be expected to produce a fracture or dislocation of a lower extremity.

For the initial tests, 6 axis load cells were attached at the upper femurs and multi axis strain gauges were installed in the lower femurs and upper and lower tibias. These were used to verify the loads up to potential fracture and to allow analysis of time-dependence and cause-effect relationships.

Knee Joint

The frangible knee assembly attaches directly to the base of the clevis of the existing Hybrid III knee, but it does not interfere with the knee in terms of flexion and extension. The design includes two brass pins which act as structural fuses, shearing when the load, in either torsion or varus-valgus rotation, exceeds the established tolerance levels. Appropriate response prior to failure is achieved by way of plastically deformable springs. Test results for the knee unit, in comparison to cadaver characteristics reported by St. Laurent et al. [3] are reported in Figures 1 and 2. The surrogate knee response curves end at the points where their respective shear pins failed. As can be seen, the strength and stiffnesses are reasonably human-like for both forms of motion. The post-failure resistance to rotation is near zero for both modes.

Leg Bones

Both the tibia and femur were constructed of composite materials. In essence, they are tubular in shape, wound with helical and axial glass fibres imbedded in a resin matrix. Bulkheads are used to prevent premature local tubular failure. Table 1 provides the results of a series of static tests in comparison with the design specifications.

Figure 3 compares the tibial force deformation characteristics of the surrogate bone to data compiled by Yamada for simply supported static bending [5].

In addition to static tests, the composite tibia has been subjected to impacts at the mid-span with a 76 mm diameter cylindrical anvil. These tests were meant to approximate the methods used by Fuller et al [6] in their dynamic tests of cadaver legs. Figure 4 compares the fracture response of the surrogate leg bone with the cadaver responses. The surrogate legbone lies within the force/time envelope of 9 cadavers and is somewhat stronger than 6 of the 9 cadavers. The time to fracture (less than 1 msec) verifies that the surrogate leg bone has an appropriate level of brittleness.

Leg Weights

The surrogate leg components were designed to have inertial properties very similar to those of a standard Hybrid III dummy. For example, the leg mass, including all components which articulate about the hip ball joint are, for the Hybrid III; 14.8 kg, for the MATD; 15.1 kg.

Lumbar Spine

The curved lumbar spine of a standard Hybrid III is designed to ensure a stable seated posture for a vehicle occupant. This curved spine does not allow enough flexibility of dummy posture for a motorcyclist ATD. A new straight spine was developed with improved static flexion-extension bending response. A comparison with available volunteer bending response data for this new spine is included in Figure 5 [7]. The new spine has been designed to be used with a six axis lumbar spine load transducer.

Abdominal Insert

The soft vinyl abdominal insert of the Hybrid III has been replaced by a crushable foam insert based on that developed by Rouhana et al. [8], but with some significant changes. The original General Motors developed insert was designed to monitor for seat belt loading to the abdomen. The insert for the MATD2 monitors for more generalized penetration into the abdominal region. This combined with the smaller volume available in this ATD, because of the changes to the lumbar spine, required a solid foam insert.

The smaller front-to-back depth of the insert reduced the ability of the insert to show deep abdominal penetration. The injury criterion used by Rouhana et al. was based solely on deformation of the abdomen and penetration equivalent to serious injury caused the MATD2 insert to bottom out. The force deflection corridors obtained by

Table 1: Design Verification, Static Tests

Component	Test	Mean (Nm)	Range (%)	N	Criteria (Nm)	Difference (%)
Femur	Static Bending	288.5	+/- 2.7	3	282.8	2
	Static Torsion	178.2	+/- 5.6	5	165.7	7
Tibia	Static Bending	241.4	+/- 6.4	8	253.3	-5
	Static Torsion	127.2	+/- 10	4	117.0	8

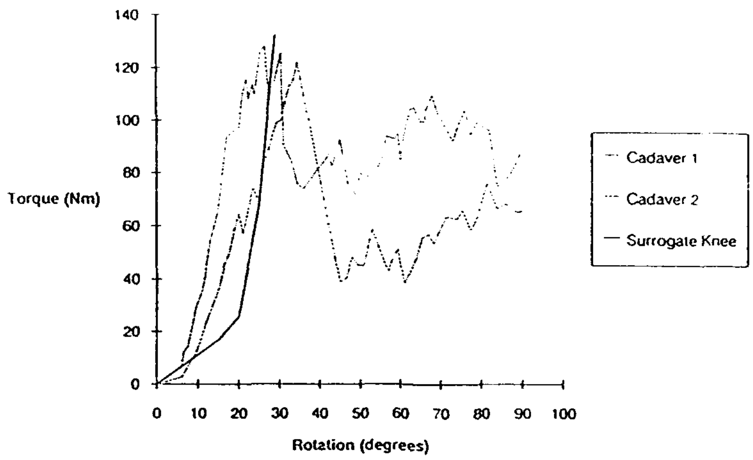

Figure 1: Response to Valgus Rotation of the Tibia [3]

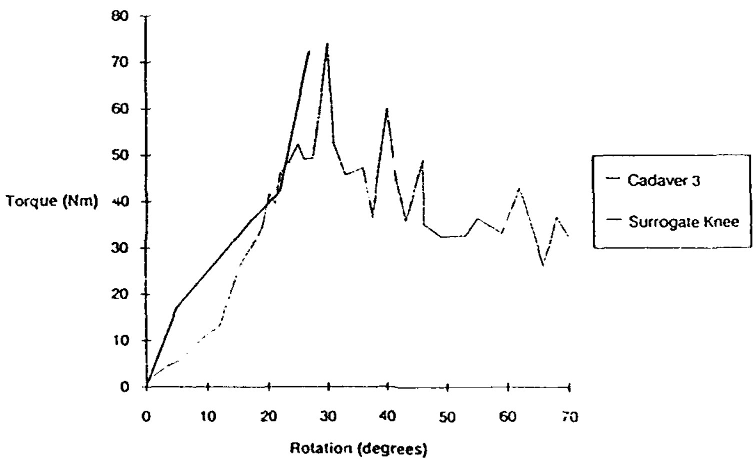

Figure 2: Response to External Torsional Rotation of the Tibia [3]

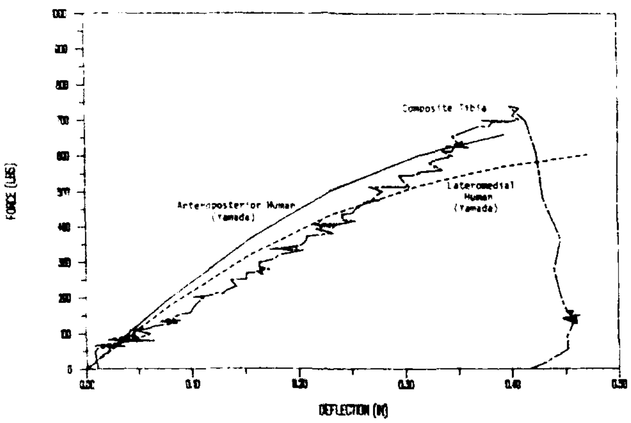

Figure 3: Tibia Force/Deflection Characteristics

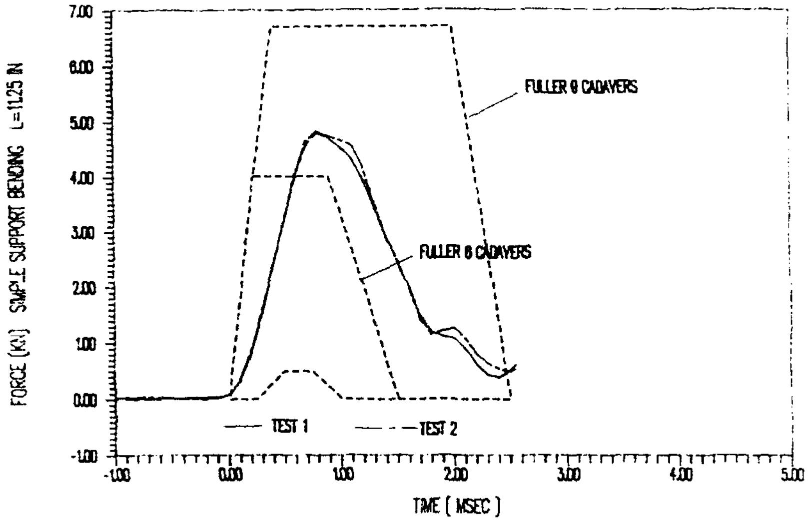

Figure 4: Composite Tibia Mid-Span Force vs. Time 76 mm Dia. Cylindrical Impactor Vel = 7.47 m/s [6]

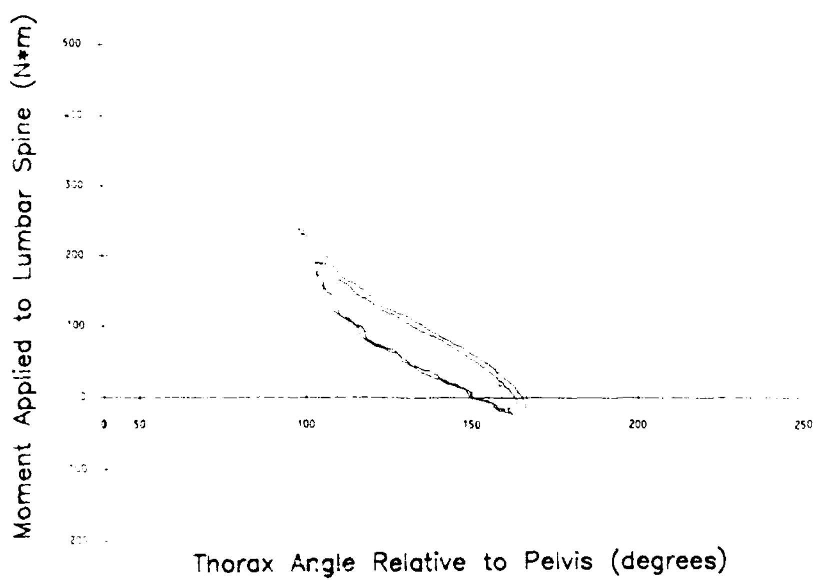

Figure 5: A Comparison of the MATD2 Lumbar Spine Static Flexion Response with Volunteer Data [7]

Cavanaugh [9], from cadaver tests were modified to compensate for this reduced penetration.
The modified performance corridors and dynamic responses of the insert are presented in Figure 6.

Chest Deflection Measurement

In the MATD1, the data acquisition system virtually filled the chest cavity. The changes made to this system for the MATD2, discussed in this paper, allowed the inclusion of an improved chest deflection measuring system. This now consists of pairs of string potentiometers triangulating the top and bottom of the sternum of the dummy. The movement of the sternum is monitored both laterally and in a fore-and-aft direction.

Neck

For a motorcyclist ATD, humanlike neck response is of vital importance in obtaining realistic kinematic and dynamic responses of the head during crashes. The performance requirements for Hybrid III head-neck response were proposed by Mertz and Patrick [10]. Neck response was defined by the relation between the torque about the occipital condyles and the position of the center of gravity of the head. Wismans et al. [11] proposed further requirements relating the angle of the head to that of the neck, based on the analysis of volunteer and cadaver test data.

The MATD2 neck has been redesigned to improve the head and neck kinematics in frontal impacts. These modifications have been aimed at allowing the dummy head to keep more vertical as it moves forward before it starts to rotate downward. The frontal responses of the modified neck are compared to the standard Hybrid III neck in Figures 7 and 8.

Figure 9 illustrates how these modifications allow the head of the MATD2 to remain more vertical than the standard Hybrid III head as they move forward in a frontal impact.

Further development is planned for the modified neck to make its compliance more closely approach to that of a human. This is required to ensure that realistic loads are generated at the occipital condyle during impact to allow the neck load transducer to be used for injury sensing. The standard Hybrid III has a neck load transducer fitted, but the output of this does not relate well to loads likely to be generated in a human neck under impact conditions. As an example of this, the testing has shown that high torsional moments (Mz) are generated in helmeted impacts by the current Hybrid III neck, yet there is little evidence of this type of injury occurring in motorcycle field accident data.

THE DATA ACQUISITION SYSTEM

The MATD2 includes a self-contained 16-channel data acquisition system. This eliminates the need for any attachment cables that, in a motorcycle crash environment, could significantly effect rider kinematics. This data acquisition system samples at 10,000 samples/second/channel and is capable of recording up to 13 seconds of data. This is important since injuries can occur during the primary car to motorcycle crash as well as during subsequent rider contact with the ground.

The system is mounted in a redesigned spine box, which is mechanically compatible with the standard Hybrid III spine box. The modified spine box weight is the same as the Hybrid III version and the full biofidelity of the Hybrid III thorax is maintained.

The sensors typically used with MATD2 include:

- 3 head linear accelerometers
- 3 head rotational accelerometers
- neck Fx, Fy and My forces and moments
- lumbar Fx, Fy and My forces and moments
- upper sternum X and Y deflections
- lower sternum X and Y deflections

The system is compatible with all commonly used dummy

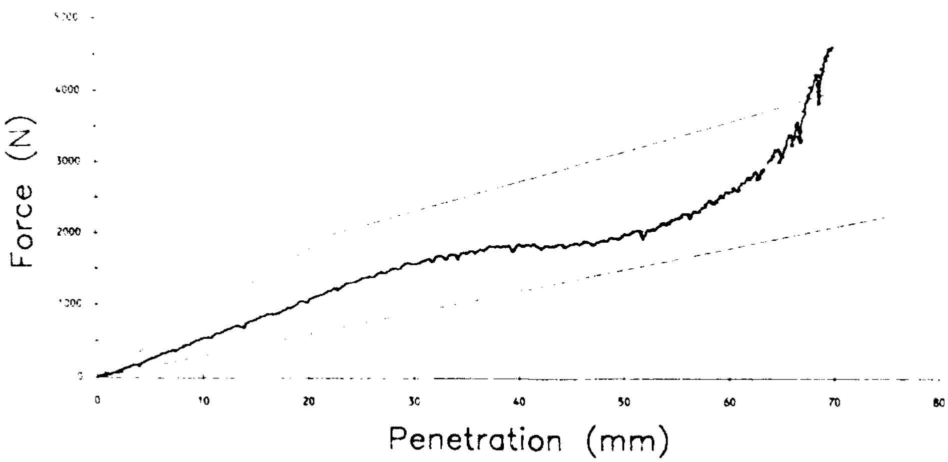

Figure 6: The Response of the MATD2 Crushable Abdominal Insert with the Modified Performance Corridors from Cavanaugh et al. [9]

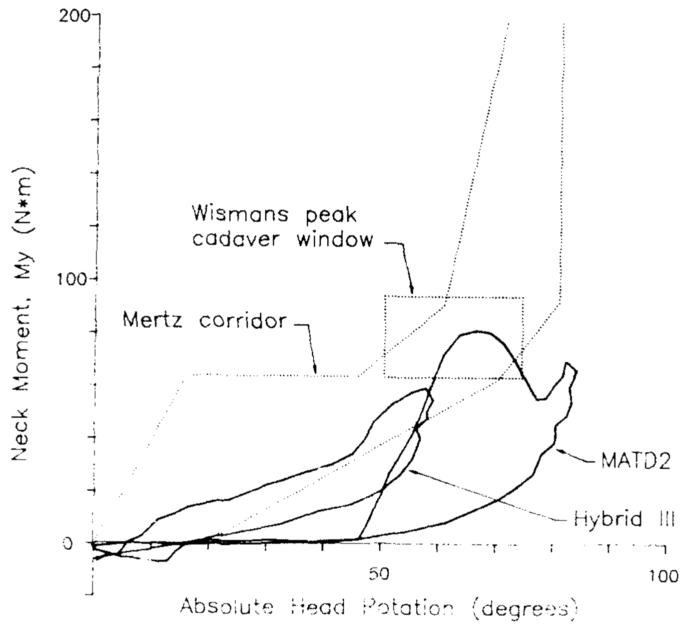

Figure 7: A Comparison of the MATD2 and Hybrid III Dynamic Neck Response with the Performance Corridors Proposed by Mertz and Patrick [8] and Wismans [9] During a Frontal Impact (17 g sled pulse)

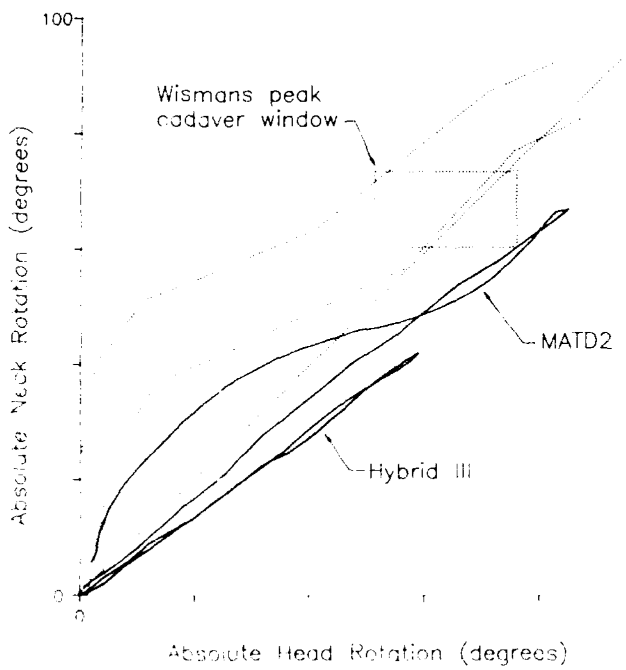

Figure 8: A Comparison of the MATD2 and Hybrid III Dynamic Neck Bending Response with the Performance Corridors from Wismans et al. [9] During a Frontal Impact (17 g sled pulse)

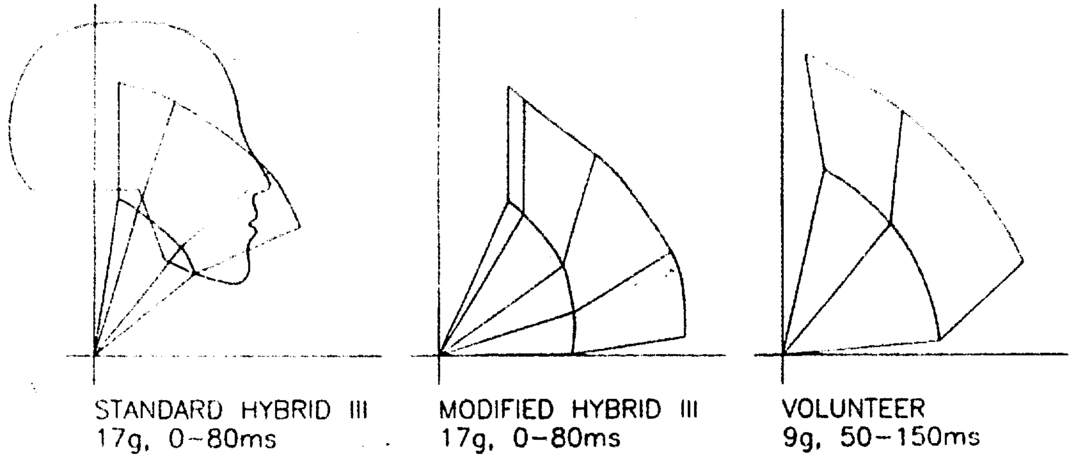

Figure 9: Absolute Head and Neck Position of the MATD2, Hybrid III and a Volunteer [11] During a Frontal Impact

load cells, potentiometers and accelerometers.

SUMMARY

The MATD2 is an ATD specifically developed for motorcycle crash testing. It is based on the Hybrid III with improvements in injury sensing capabilities and biofidelity. These changes, and the inclusion of a self-contained data acquisition system, make it appropriate for use as an aircraft crash test dummy.

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THE APPLICATION OF A HYBRID III DUMMY TO THE IMPACT ASSESSMENT OF A FREE-FALL LIFEBOAT

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Summary

A requirement to monitor occupant forces during the launch of a free-fall lifeboat has led to the definition of a transportable instrumented dummy and data-acquisition system.

Good quality data have been record during 21 free-falls from which advice has been given concerning the acceptability of launch forces for both injured and non-injured personnel.

Head restraint is not considered in the International Maritime Organisation's current assessment criteria for free-fall lifeboats, but was shown to have a pronounced effect on head and neck forces, with significant overshoots being seen when no restraint was available.

It is concluded that the dummy and data-acquisition system developed for these trials offers a valid means for assessing impact forces and injury risk in novel impact environments such as the launch of a free-fall lifeboat.

Introduction

The concept of launching a lifeboat by free-fall, rather than by conventional use of davits, was patented in Sweden in 1897, but the first practical boat was manufactured by Verhoef Aluminium Sheepsbouwindustrie only in 1960. The technique has become widely accepted in the last decade.

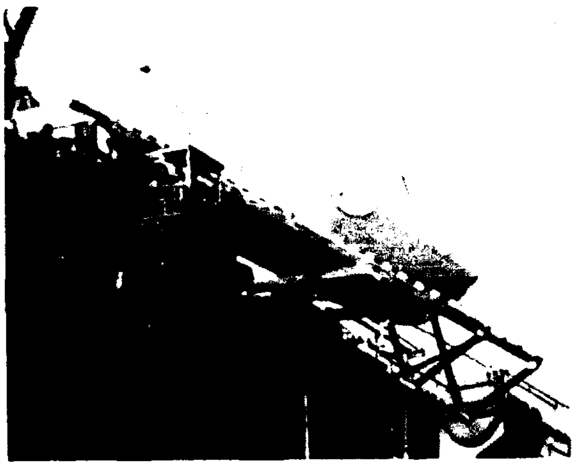

Fig. 1. A free-fall lifeboat ready for launching from a cradle on a semi-submersible oil drilling rig.

The principle is straightforward - the fully manned lifeboat is launched from a cradle attached to a cargo ship, tanker or oil platform, the cradle supporting it bow down by 35° or so (Fig. 1). Upon release, the lifeboat runs forward under gravity, leaves the cradle and plunges a vertical distance of up to 30 m to enter the sea bow first (Fig. 2).

Fig. 2. Free-fall lifeboat just prior to water entry following a launch from a height of 33 m.

Appropriate hull design can ensure that, after a brief period of submersion, much of the kinetic energy gained in the free-fall is converted into forwards motion, so that the boat finishes up 100 m or more from the point of impact, even without the use of engine power.

Advantages of a free-fall launch, in addition to the rapid separation from parent ship or rig, include the ability to launch without outside assistance, the simplicity and reliability of the launch mechanism (basically gravity), and the use of the necessarily sealed hull to provide sustained protection from fire and toxic fumes. However, a potential disadvantage is that the forces induced by water entry might cause injury, or exacerbate an injury caused earlier in the primary emergency.

Currently, acceleration forces induced in a free-fall lifeboat launch are assessed by criteria recommended by the International Maritime Organisation (IMO) and recently clarified in reference 1. The Combined Acceleration Response (CAR) is the maximum value for the square root of the sum of squares (SRSS) of the accelerations simultaneously measured in the three co-ordinate body axes, expressed as ratios to the 'acceptable' limits of $\pm 15G_x$, $\pm 7G_y$ and $\pm 7G_z$. While the SRSS approach appears intuitively logical: it has not been validated experimentally; the chosen limits could be excessive, especially in the y axis; somewhat questionable 'not less than' 20 H_z low-pass filtering is applied to all data; and most important, the limits are applied independent of seat orientation, or of seat or restraint harness configuration.

The Combined Dynamic Response Ratio (CDRR) also applies the SRSS technique, but this time not to peak acceleration values, but to dynamic response indices in the three axes as developed by Brinkley (1985). The Dynamic Response Index (DRI) was originally developed to assess the risk of spinal compression injury during the very high peaks and onset rates of $+G_z$ accelerations induced in aircraft ejection seats, and its extension to the other five axial directions ($-G_z$, $\pm G_x$ and $\pm G_y$) has not been validated. As well as the criticisms already mentioned in relation to the CAR, a further element of uncertainty is introduced as the limits used in calculating the CDRR are based on either low (0.5%) or moderate (5%) risk levels as defined for assessing aircraft ejection systems. In these, the additional acceleration vectors are induced largely by windblast forces rather than through a seat and harness system, and the application of these values to a free-fall lifeboat launch is problematic, particularly if no recognition is to be given to the presence or absence of head restraint. Also it is debatable whether even a 0.5% risk of injury would be acceptable for routine training of potential lifeboat users.

Doubts concerning the validity of either the CAR or CDRR led us, in discussions with representatives from the Department of Transport (Marine Directorate) and the Health and Safety Executive (Offshore Division), to consider alternative means for assessing the potential for injury in free-fall lifeboat launches, particularly in relation to the evacuation of already injured personnel. Recent developments in the biofidelity of anthropometric dummies, and the availability of relatively portable and robust solid-state data acquisition systems, led to the use of an instrumented Hybrid III dummy in preliminary tests and to the subsequent use of this method in evaluating the impact characteristics of free-fall lifeboats from three manufacturers.

Methods

Initial tests were conducted using a FL24 lifeboat (Verhoef Aluminium Sheepsbouwindustrie) at the Maritime Training Centre (MTC) facility in Rotterdam, Holland. The MTC training rig offers a 16.5 m drop height and its associated cabin and docking facilities made checking out, calibration and installation of the test equipment relatively straightforward. It also offers the advantage of a rapid turn round, as little as 20 min between launches.

The dummy was a standard 50th percentile Hybrid III (Humanetics Inc) instrumented with 9 transducers as follows:

Site	Transducer	Axis
Head	Philips PR 9367/50 accelerometer	G_x
Head	Philips PR 9367/50 accelerometer	G_y
Head	Philips PR 9367/50 accelerometer	G_z
Torso	Kyowa AS/50 accelerometer	G_x
Torso	Philips PR 9367/50 accelerometer	G_z
Pelvis	Philips PR 9367/50 accelerometer	G_z
Lower neck	Robert Denton 6 axis model 1794 load cell	F_x
Lower neck	Model 1794 load cell	F_z
Lower neck	Model 1794 load cell	M_y

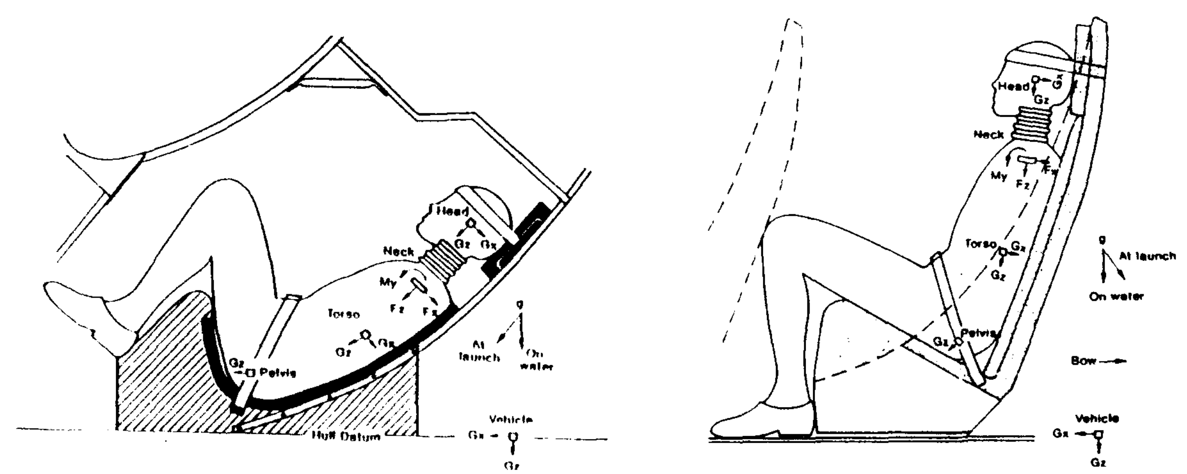

Fig. 3. Dummy installed in seats showing orientation and location of transducers. Left, forward facing and right, rearward facing seat configurations.

A further three Kyowa AS/50 accelerometers were mounted in a block and bolted to the hull structure so as to record accelerations in the boat's G_x, G_y and G_z axes. Note that these vectors differ from those of the dummy as indicated in figure 3, that they also depend on seat orientation, and that the 1g gravity vector rotates through 35° between launch and recovery, having achieved an even greater offset at the instant of water impact (see figure 2).

Outputs from the accelerometers and load cells were fed to a 13 channel strain gauge measurement system, Micro Movements Ltd M1000 series, and thence to a ruggedised data acquisition unit, a Kayser Portax AT 286/20 computer using Global LAB software.

The system was set up and calibrated at the RAF IAM, then dismantled and loaded into a car for shipment to Rotterdam. It was off loaded and hand carried onto the MTC facility's deck where it was set up and bench tested using MTC's 220v electricity supply, the head and hull (vehicle) accelerometers being checked against ± 1g inputs using Earth's gravity. The equipment was rechecked using a pair of 12 v lead acid batteries before being separated into its components for transfer to, and installation in the lifeboat. The definitive calibration of the force transducers was carried out in the laboratory upon return to the UK, the accelerometers being individually calibrated at 10G using a small (241 mm radius) centrifuge, while the neck load cells were calibrated using the manufacturer's published sensitivity data. The zero base line for all transducers was taken as the period of free-fall prior to impact, though neck forces may still have been present due to tension in the restraint harness and hysteresis in the dummy neck.

Because of the complex pattern of impact forces, and their variation down the length of the hull caused by the lifeboat's rotation on water entry, drops were recorded with the dummy in two seat locations. For the first series of tests the dummy was strapped into the lower forward seat on the port side with the amplifiers and computer mounted on Plastazote foam on an adjacent seat. The vehicle accelerometer was fixed on a line with the dummy's chest using an existing floor plate bolt. The computer was triggered some 2 s into the release sequence using a hand-held button. After two successful launches and recordings, the dummy was transferred to the rearmost seat on the port side. The electronics were moved and refixed to an adjacent seat and the vehicle accelerometer mounted on a piece of aluminium channel pop-riveted to the floor in the centreline just forward of the battery box. This series of tests was completed in April 1991, since when three further series of tests have been undertaken.

Five tests were carried out on a larger, 45 person, free-fall lifeboat using a launch platform built onto the deck of a semi-submersible crane barge, the Hermod, anchored in Rotterdam harbour, with drop heights of up to 31.3 m; and eight on a similar sized Norwegian-built craft and a rig attached to a semi-submersible oil drilling platform. A final series of four tests was monitored using a different dummy (another Hybrid III), transducers (Endevco Model 7264-200 piezoresistive accelerometers) and data acquisition system (a Fastbox developed by the Texas Transportation Institute). These were carried out on a British built lifeboat using a dockside tower in Europort, Rotterdam, from drop heights of up to 25.8 m.

Results and Discussion

Good data were obtained from all 21 tests referred to above, but two additional tests had to be repeated following failure to trigger the data-acquisition system, and one following an earthing fault caused by abrasion of a makeshift DC supply cable. In the final series, individual data channels were lost following ingress of sea-water and the wetting of connectors.

Triggering of the data-acquisition system posed a continuing problem due to the short recording time available and the variable, and sometimes lengthy, interval between the release command and the physical release of the lifeboat. The first tests were manned and one of us rode the boat down and actuated the trigger manually during the pre-release countdown. Bounce of the button contacts caused two recording failures and thereafter the computer keyboard was utilised. For the second and third series of tests, which were largely unmanned, an external trigger was used. This was taped to the hull and actuated manually just prior to boat release, though with an inevitably variable time delay. For the final tests the Fastbox was operated by a switch and static line, a technique which precluded any record of the pre-release 1 g conditions, useful as a calibration check (see below). This system only provided 5 s of usable recording time and with a 3 s delay between release and water impact, the later phases of the launch oscillations were unrecorded.

Sea-water contamination posed a serious problem in later tests in which leaks occurred through access doors and hatches. Indeed, concern about potential flooding led to the serendipidous removal of the dummy and instrumentation prior to an overload test in which the lifeboat's access door failed.

Calibration of the equipment was based upon manufacturers' sensitivity data, and confirmed by use of a small radius centrifuge at the RAF IAM, and by the ±1g checks on accelerometers on site. However, these latter checks necessitated stripping down the dummy to remove the accelerometers and were only used in the first tests as it was subsequently found that calibrations at the RAF IAM before and following a series of tests (and associated manhandling of the dummy) were in close agreement - usually within 2%. A final check on the system was obtained by calculating the angle of the launch ramp from $+G_z$ data recorded pre-release, and during the phase of weightless free-fall (see figure 4, arrow B). A value of 34.4° was obtained which compares very satisfactorily with the actual 35° at which the ramp was constructed.

Figure 4 illustrates lifeboat accelerations in the x and z axes recorded from the hull at forward and aft locations. The y axis data are omitted since, with one exception (see below) they were insignificantly small. While the general shape of the pulses is similar: a $-G_x$ pulse as the craft slows down along its longitudinal axis over a period of 1 s, from an initial impact velocity of 18 ms^{-1}; and a $+G_z$ pulse as the bows are forced upwards and the stern brought to rest following rotation of the vessel; the pulse profiles, and in particular, the initial spikes on first water contact, are significantly different. Thus, the lifeboat is initially rotated about its centre of mass, causing a $-G_z$ spike at the aft seating position and a $+G_z$ spike forward. The main acceleration pulses are of low magnitude, $-2G_x$ and $+5G_z$, but peaks seen in the 125_z low-pass filtered signal range from -4 to $+0.5G_x$ and from -4.5 to

$+8.5G_z$. It is these peaks, in particular, which evoke dynamic responses from the dummy. Secondary oscillations are seen in the G_z axis as the boat re-emerges from the water and is briefly weightless again before finally coming to rest some 5 s following the initial impact.

Figure 5 illustrates traces of forces recorded in the dummy in the G_x axis - head, torso, neck F_x (shear in the x axis) and neck M_y (the moment tending to nod the head), and figure 6 shows equivalent data for the G_z axis - head, torso, pelvis and neck. In both figures the simultaneously recorded hull accelerations are shown and major differences are caused by the differing orientations of the accelerometers (left hand panel, Fig. 3). There was little evidence of dynamic overshoot in these particular tests in which the torso and head were efficiently restrained. Quite considerable neck forces were seen with, as would be expected with head restraint, the pattern of neck F_x closely following head G_z (though inverted in figure 6). The neck moment about the y axis (M_y) exhibited peaks in excess of +700 and -400 lb ins (Fig. 5).

The later boats tested required a somewhat extended head position in order to obtain head contact with the head rest and this attitude could not be achieved within the range of adjustment of the Hybrid III dummy neck. Consequently, head restraints could not be utilised, even when provided. In general, neck forces were moderately high, and head accelerations relatively low, when head restraints were used; while without restraint the neck forces were lower, but the head acceleration data showed greater dynamic overshoot.

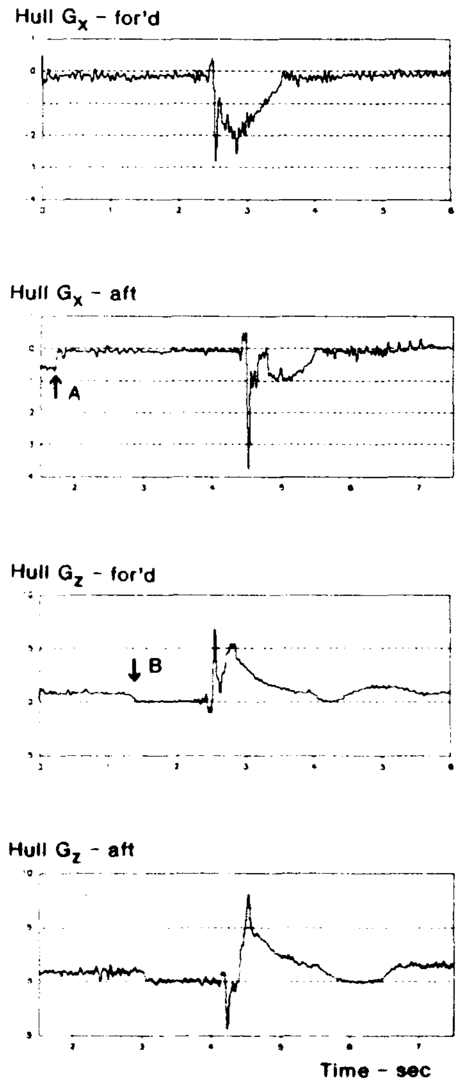

Fig. 4. Effect of accelerometer location on hull forces. The lifeboat is released at point A and clears the ramp at point B.

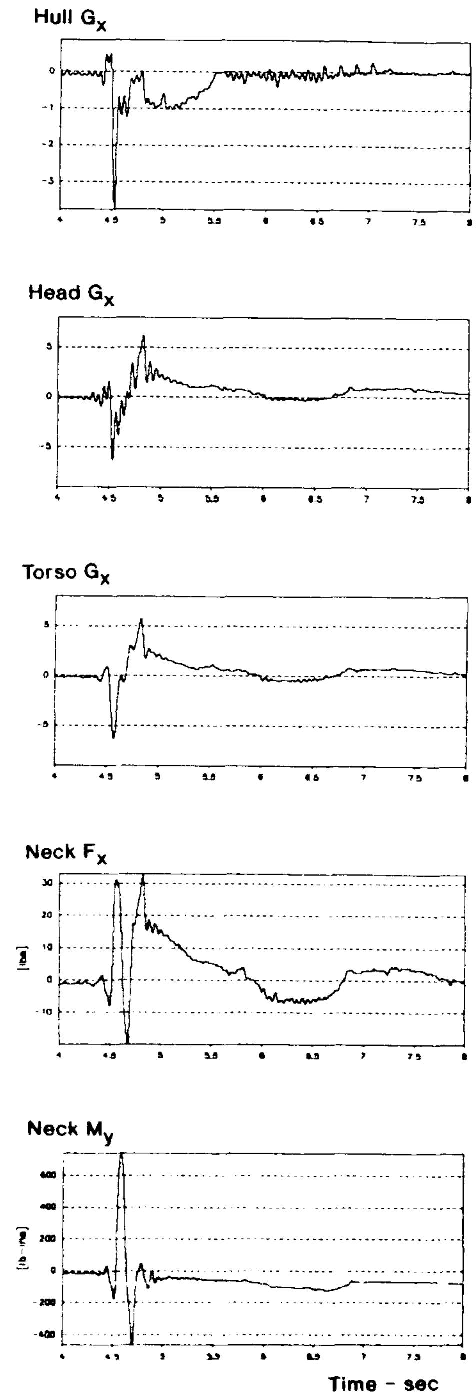

Fig. 5. Hull and dummy G_x axis forces recorded during a lifeboat launch from 16.5 m, aft seating position, forward facing seat.

One of the lifeboats tested showed consistent lateral hull accelerations which ranged from +0.8 to $2G_y$, and these induced head accelerations of up to $-7G_y$. (The change in sign is due to a rearward facing sitting position). Head restraint was not provided in this lifeboat and, as illustrated in figure 7, considerable dynamic overshoot occurred in both G_z and G_y axes. If the CAR were to be calculated from head data, rather than from hull data, a value of approximately 1.4 would have been obtained, so exceeding the allowable value of unity. The hull measurements yielded an acceptable CAR of 0.85. This observation confirms the relevance of the dynamic response and suggests that any index used to assess the lifeboat's acceleration characteristics should take this factor into account. Thus, the CDRR is preferable to the CAR in this respect.

A video recording was made of the dummy during one launch in which the harness was deliberately left slack. During the free-fall phase of the launch, the dummy rose out of its seat to the limit of its restraint, so confirming the need for a torso restraint system which will be effective even when donned rapidly in an emergency evacuation. Clearly, serious injuries could be caused if any passenger were to be launched unrestrained, even in a rearward facing seat.

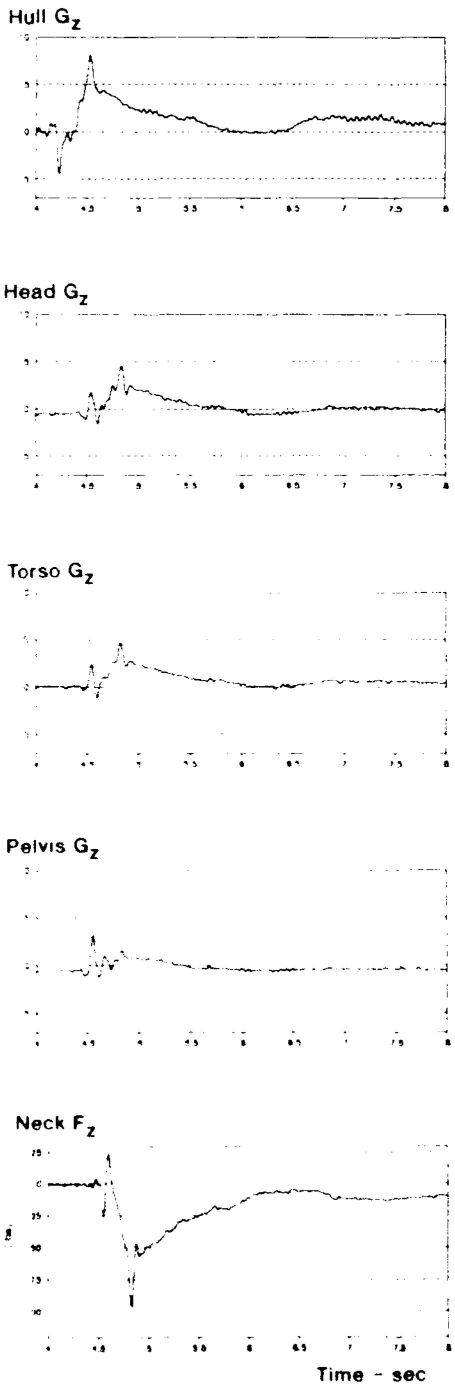

Fig. 6. Hull and dummy G_z axis forces recorded during a lifeboat launch from 1o.5 m, aft seating position, forward facing seat.

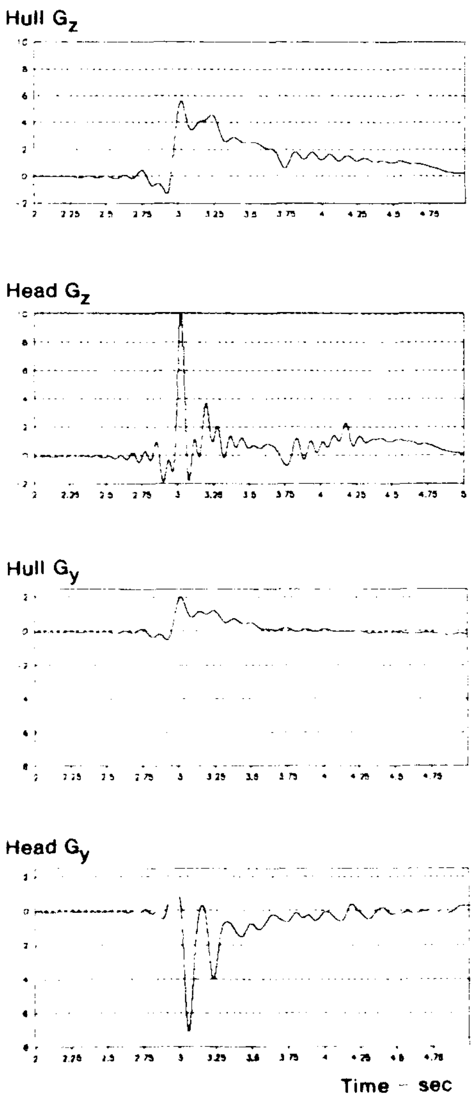

Fig. 7. Transmission of forces from hull to head in the Z and Y axes recorded during a launch from a height of 25.8 m. Rearward facing seat, no head restraint.

Lifeboats evaluated incorporated both forward and rearward facing seats, and either configuration appears adequate given effective restraint. There were three different harness arrangements, with and without head restraint. Consideration should be given to evaluating these restraint systems on an impact rig using human volunteers and representative acceleration pulses. Such tests would also provide a useful and realistic validation of the dummy impact data, and add to the limited personal experience of free-fall launches obtained by the authors during these trials.

In only one instance had the carriage of injured personnel been referred to by the manufacturer at the time of the trial. Where a stretcher is proposed to be fitted in the gangway, an instrumented dummy would be the ideal means for assessing the potential for pre-existing limb and neck injuries to be exacerbated by the impact forces.

Lower limb force transducers were not available at the time of these trials, but subsequent use of the Hybrid III dummy on ejection rig tests has shown the value of a 6-axis femur load cell in assessing limb loadings. Its use is strongly recommended for future free-fall lifeboat evaluations, particularly in relation to the use of stretchers.

No attempt has been made in this paper to relate measured forces to the many human tolerance figures available in the literature - for example the 1985 Michigan University Review of Biomechanical Impact Response (3). Suffice it to say that many data are available against which the measured values can be assessed in terms of injury risk, a direct approach which offers a significant advance over the use of simple mathematical models such as the CDRR (4).

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A NEW INSTRUMENTATION SYSTEM FOR MEASURING THE DYNAMIC RESPONSE OF THE HUMAN HEAD/NECK DURING IMPACT ACCELERATION[1]

by

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SUMMARY

Recently developed angular motion sensors, based on the laws of magnetohydrodynamics, have potential application in biodynamic research. These sensors were tested on the Naval Biodynamics Laboratory's (NBDL) vertical accelerator, using the Hybrid III manikin as the test subject. The sensors were used to measure the manikin's head motion in three dimensions. Experiments were conducted at impact levels up to 13g in the vertical (+Z) direction. Data was collected using both the new sensors and the standard NBDL package of nine linear accelerometers. A new method for obtaining initial position and orientation information using still photogrammetry was also evaluated.

The analyses of the tests show that the new sensor and photogrammetry system compared very well with the nine accelerometer array and the direct photographic measurement of displacement. Comparisons were made between measurements of acceleration, velocity and displacement. The new system yielded equivalent and, in some instances, more accurate results. This study extends the results of previous preliminary testing and confirms the value of the new system as a simpler, more accurate and portable replacement for the old one.

INTRODUCTION

At the NBDL we conduct simulated crash and ejection tests utilizing human subjects as well as manikins. Analyses of these tests require a validated data acquisition and processing system. The two principal requirements for such a system are the accurate measurement of:

1. the relative positions and orientations of coordinate systems based on anatomical and instrumentation landmarks;
2. the time history of the anatomical kinematic variables which include linear and angular velocity, acceleration, and displacement.

For this series of comparison tests we used the NBDL sled coordinate system and the head anatomical coordinate system [1]. We measured the linear and angular motions of the head with arrays of subminiature accelerometers. Nine transducers were used in three triaxial clusters, an arrangement commonly described as the 3-3-3 configuration [2]. Anatomical coordinates and instrumentation location were measured in this, the "old" system, by X-ray photogrammetry [3]. High-speed cinematography provided direct measure of displacement, as well as coordinate, initial position and velocity information.

Recently an angular motion sensor, based on the laws of magnetohydrodynamics, was developed by Applied Technology Associates (ATA). Preliminary evaluations of this sensor both at NBDL and at the Transportation Research Center of Ohio yielded encouraging results [4,5]. These tests, however, were limited in scope and did not address the issue of incorporating the new sensor into a new complete system, with total measurement capability equivalent to the old system. The new system we describe here is such a complete one. In addition to incorporating the new sensors, it uses 35 mm still camera photos for locating coordinates, instrumentation, and initial position.

To evaluate the performance of the new system, we performed seven impact tests using the NBDL vertical accelerator facility and an appropriately instrumented Hybrid III manikin as the subject. Tests were made at impact levels up to 13g in the vertical (+Z) direction.

EXPERIMENTAL METHOD

Coordinate and target location. The new head anthropometry procedures used six simultaneous 35 mm still photos of the manikin wearing NBDL standard mouth instrumentation [2]. Film coordinates of the markers positions were obtained from enlargements using an ALTEK® digitizer. Customized versions of PREP® and PC-GIANT®, two standard photogrammetric software packages, were used for the three-dimensional (3-D) reconstructions of marker positions.

This new system yielded point positions accurate to ±1 mm with up to four degrees of freedom for error estimation. The old system yielded a minimal solution with no degrees of freedom for error estimation (i.e., only two ray intersections). The best features of the new methodology are the lack of X-ray exposure for human subjects, greatly enhanced portability, increased accuracy and error estimation capability.

To compute initial conditions for the head kinematic variables, the positions and orientations of the cameras with respect to the laboratory coordinate system had to be located. In the old system, a theodolitic survey was used to locate the corners of each camera mounting block. The location of the camera coordinate systems in the laboratory coordinate system were then determined by combining this site survey data with camera calibration data [6].

In the new system, six 35 mm cameras were mounted on a stationary frame on the vertical accelerator, two on each side of the manikin and two in front. Each had an unobstructed view of a large number of control points and the expected range of positions of targets on the test subject. A calibrated 3-D target system (a "spider") [7]

[1] Opinions or conclusions contained in this report are those of the authors and do not necessarily reflect the views of, or have the endorsement of the Department of the Navy. Trade names of materials or products of commercial or other non-government organizations are cited only where essential to precision in describing research procedures or evaluation of results. Their use does not constitute official endorsement or approval of the use of such commercial hardware or software.

was attached to a previously surveyed target cube and the transformation from the spider to the laboratory system was obtained. Six simultaneous photos of the above setup were taken. The negatives were digitized on a Mann Comparator® and processed through PREP® and PC-GIANT®. Site survey results included the positions and attitudes of the six cameras, the locations of the eight corners of three target (control) cubes and several survey targets at various locations on the test platform.

The 35 mm cameras used in both the head anthropometry and site survey were calibrated and corrected for radial and tangential lens distortion [8].

Kinematic variables. The generation of time traces for the head kinematic variables require: 1) the relations among the coordinate systems determined by the head anthropometry, site survey, and camera calibrations; 2) stable mathematical algorithms for deriving those variables not directly measured by the cameras and inertial sensors and 3) initial values for the kinematic variables computed by these algorithms.

The old system computes initial head linear and angular displacements and velocities using approximately 50 ms of photodata acquired prior to first motion by the three high speed cameras. Angular initial conditions are derived in quaternion form. Euler angle and direction cosine matrix initializations are obtained via standard conversion formulas [1,2]. Initial accelerations are arbitrarily set to zero.

The new system computes the initial displacements from a set of six simultaneous 35 mm still photos acquired prior to first motion. Initial velocities and accelerations are set to zero.

In the old system, the linear and angular displacements of the mouth instrumentation with respect to the laboratory are computed using a non-linear least squares algorithm [9] on two-dimensional photodata from the three high-speed cameras. Angular and linear velocities are obtained by differentiation of the displacement data. Linear accelerations of the mouth instrumentation are obtained from a linear accelerometer triad placed at the instrument origin. Angular accelerations and velocities are computed using appropriate differences of linear accelerometer measurements from the three triaxial clusters (3-3-3 accelerometer package) and Euler's equations. The available redundancy in equations is exploited to compute a "best" least squares solution for the accelerations and velocities. Linear velocities are obtained by integration of the linear accelerations.

Data quality is assessed by the degree of overlay of the photo and accelerometer-derived linear and angular velocity plots.

In the new system, linear accelerations of the mouth instrumentation are measured as in the old system. Repeated integrations produce the corresponding velocities and displacements. The redundancy of the new linear accelerometer and angular velocity sensor system allows the determination of optimal linear acceleration values which yield stable, reliable velocities and displacements.

Angular velocities about the X, Y and Z axes of the head coordinate system are measured by three orthogonal angular velocity sensors. Angular accelerations are obtained by using a 5 point differentiator on the measured angular velocity data. Angular displacements are obtained by applying a 4th order Runge-Kutta method to the linear variable-coefficient differential equations for quaternion time evolution [10]. The measured angular velocities are the coefficients for this system of equations. Best results for this algorithm were obtained by "normalizing" all quaternions appearing in the Runge-Kutta formulas for each time step rather than forcing normalization by penalty functions [10].

Test configuration. All tests were conducted using a Bendix Hyge .1524 m (6") diameter pneumatically driven accelerator and NBDL's vertical payload carriage.

The manikin was restrained in a nominally upright seated position by shoulder straps, a lap belt and an inverted-V pelvic strap secured to the lap belt. Wrist restraints were used to prevent flailing of the arms. Data was collected using NBDL's standard channels (125 Hz, 2000 samples/second/channel). **Figure 1** is an illustration of the overall test configuration.

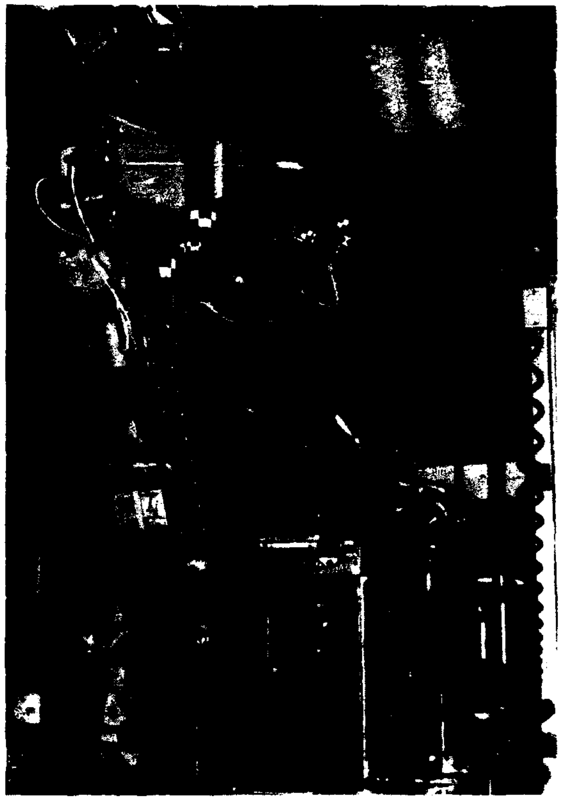

Figure 1 Experimental setup.

The old and new system were evaluated by fitting the Hybrid III manikin with two head instrumentation packages: the 3-3-3 accelerometer package (called T-Plate for its shape), and a three-dimensional measurement package consisting of a triaxial linear accelerometer cluster and three orthogonal angular velocity sensors (called Triax-ATA).

All accelerometers were Entran EGA series subminiature piezoresistive units with a dynamic range of $\pm 50g$ and a nominal sensitivity of 3 mv/g. The angular velocity sensors were ATA ARS-l sensors, which had a dynamic range of ± 1600 rad/s and a nominal sensitivity of 6 mv/rad/s. The T-Plate, which doubles as a phototarget carrier, was firmly attached to an interface fixture bolted to the manikin's chin (as seen in **Figure 1**). The Triax-ATA package was bolted to the base of the manikin's head using a package illustrated in **Figure 2**.

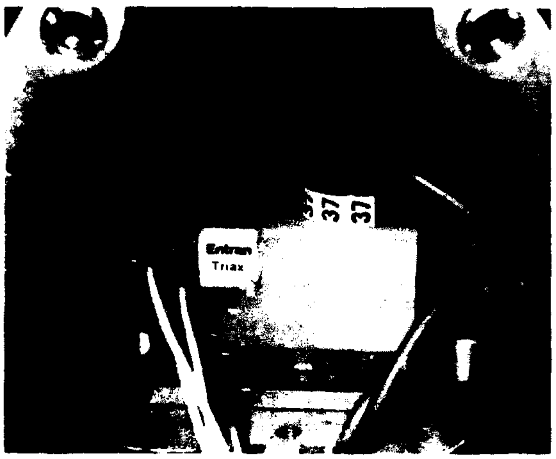

Figure 2 Triax-ATA mounting package.

The measurements from this package were made in the coordinate system defined in **Figure 3**, where the arrowheads indicate the direction of positive motion. Measurements from the T-plate cluster were transformed to this same coordinate system to allow a direct comparison of the motions recorded by both systems.

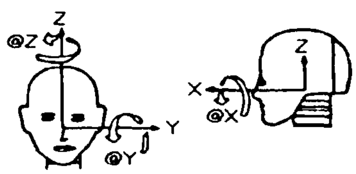

Figure 3 Manikin Coordinates

The new system's still photography and the old system's high speed cinematography were also used for measuring initial position and displacement. This configuration allowed the following comparisons: Triax-ATA vs T-plate; T-plate vs photodata; and Triax-ATA vs photodata.

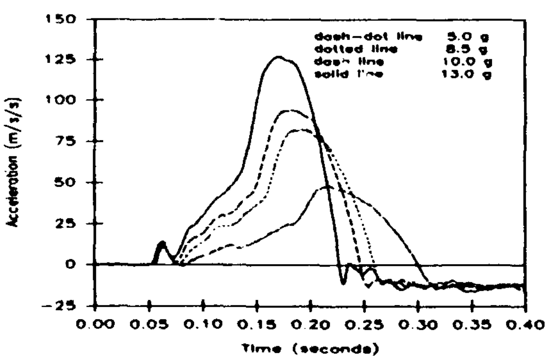

Figure 4. Typical sled acceleration profiles.

Figure 4 illustrates typical time traces for accelerations ranging from 5g to 13g. The basic parameters include peak sled acceleration, endstroke sled velocity, rate of acceleration onset, and duration of peak acceleration. These are summarized in **Table 1**.

Comparison analysis. All kinematic variables (linear and

Peak (m/s^2)	Endstroke velocity (m/s)	Rate of onset (m/s^3)	Duration (ms)
48.4	4.8	601	62
82.9	6.8	2194	59
94.5	7.5	2540	58
125.3	9.3	3538	53

Table 1 Sled Acceleration Parameters

angular acceleration, velocity and displacement) were compared between the new and old systems. At each acceleration level, differentiated angular sensor outputs were compared with the computed angular accelerations of the T-plate. For the T-plate, NBDL's standard procedure was used. This takes advantage of the available redundancy in equations to compute a best least-squares solution for the angular accelerations and the linear accelerations of the mouth T-plate origin. For the new system, only the linear acceleration of the origin is computed via least squares. The angular accelerations are computed by differentiating the angular velocity measurements.

At the velocity level, the computed angular acceleration measurements were mathematically integrated and compared with the direct measurements obtained from the ATAs. The angular trajectories obtained from the high speed cinematography were also differentiated and compared to the ATA outputs. The computed linear acceleration measurements of the T-plate origin for the new and old systems were integrated and compared to differentiated linear displacement photodata from high speed cinematography.

At the displacement level, angular displacements about the X, Y and Z axes of the head anatomical system obtained by high-speed cinematography were compared with computed angular displacements obtained from integrating the quaternionic equations of motion and subsequent conversion to Euler angles. Linear displacements of the T-plate origin obtained from high-speed cinematography were compared to the linear displacements computed by integration of the computed linear velocities of the new system.

RESULTS

Due to the stiffness of the manikin neck, there was no significant head motion outside the mid-saggital (X-Z) plane. Consequently, the linear kinematics reviewed here include: X and Z displacements (Xd, Zd), velocities (Xv, Zv) and accelerations (Xa, Za). The rotational kinematics about the Y axis (@Y) include angular displacement (@Yd), angular velocity (@Yv) and angular acceleration (@Ya).

Individual and overlay plots of old and new @Ya, @Yv and @Yd for a 13g test, are shown in **Figures 5-7**. **Figures 6** and **7** include an unfiltered plot of @Yv and @Yd computed from the old high speed cinematography as a reference standard.

Figures 8-11 show overlay plots of old and new Xa, Za, Xv and Zv respectively. **Figures 12 and 13** are plots of the old and new displacement measures, Xd and Zd. The velocity and displacement plots (**Figures 10-13**) include an unfiltered reference computed from the old high speed cinematography.

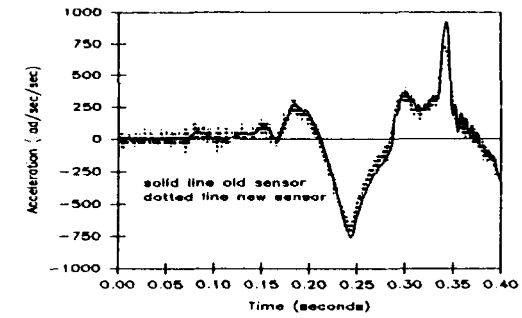

Figure 5: Old and New Y-axis angular acceleration

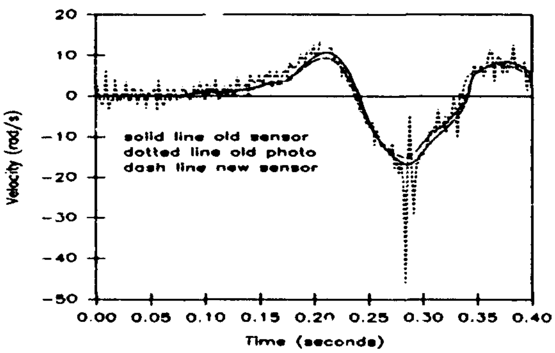

Figure 6: Old and New Y-axis angular velocity

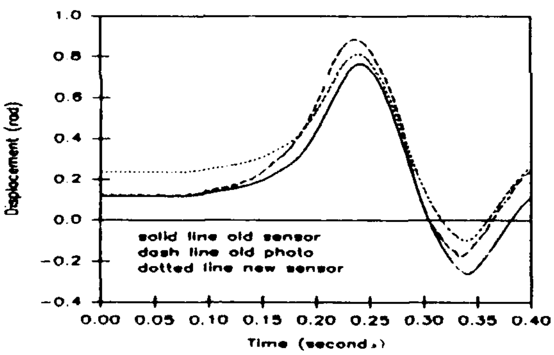

Figure 7: Old and New Y-axis angular displacement

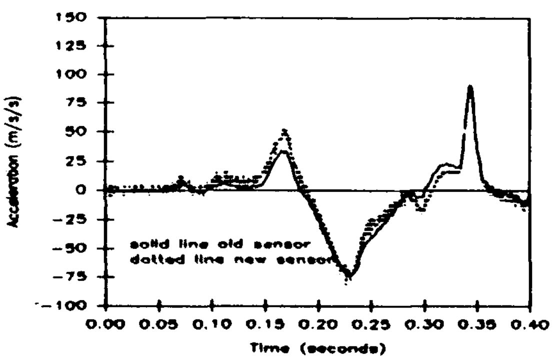

Figure 8: Old and New X-axis linear acceleration

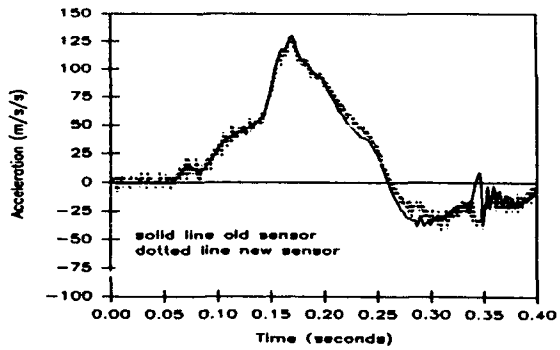

Figure 9: Old and New Z-axis linear acceleration

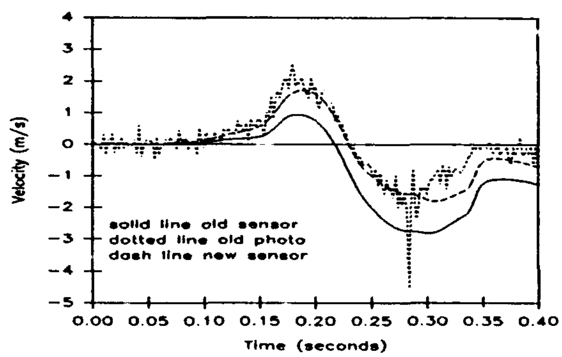

Figure 10: Old and New X-axis linear velocity

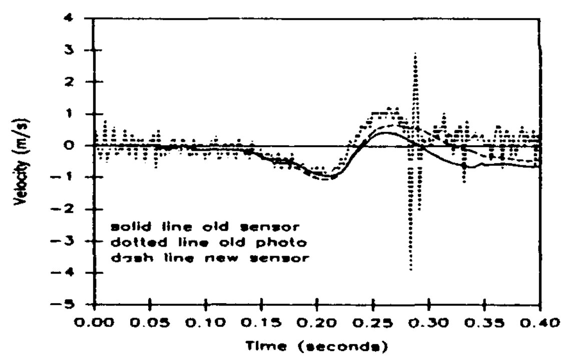

Figure 11: Old and New Z-axis linear velocity

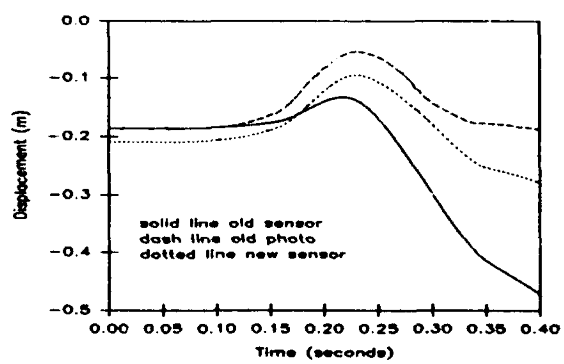

Figure 12: Old and New X-axis linear displacement

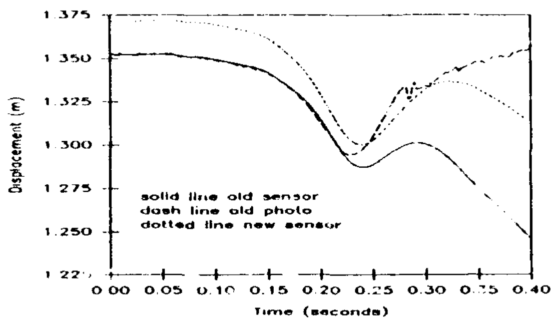

Figure 13: Old and New Z-axis linear displacement

DISCUSSION

Figures 5-13 present the comparisons of the midsagittal head kinematic variables measured by the old and new system for a 13g +7 vertical test. It is evident from **Figure 5-6** that the ATA sensors yield angular acceleration and velocity measurements matching those produced by the old system. The differentiated angular displacement photodata provides an independent confirmation of the accuracy of the velocity measurements. For the angular displacement in **Figure 7**, the photo data is the direct measurement. The new sensor derived angular displacement agrees excellently with the angular displacement photodata. The discrepancy in initial displacement at zero time between the old photo and the new sensor is due to the two different photogrammetric systems - high speed cameras vs 35 mm cameras - used to obtain the initial conditions.

The excellent performance of the new system in deriving the angular kinematics is not surprising. Since angular velocity is directly measured, a single differentiation or integration leads to the corresponding angular acceleration and displacement. However, the linear kinematics are another matter. As **Figures 8-9** illustrate, there is excellent agreement between the new and old head linear accelerations. However, at the velocity and displacement levels, (**Figures 10-13**), the new sensor system tracks the photo derived velocities much more closely than does the old system. The displacements measured by the new system (accounting for differences in initial position) track the photo derived displacements extremely well up to 350 ms, while showing far less divergence than the old system displacements.

The improved accuracy of the new system is due to the direct measurement of angular velocity, using differentiating to obtain acceleration. The old system uses a bootstrap least-squares algorithm for deriving head linear and angular accelerations and velocities [1]. This procedure leads to the accumulation of small errors which results in an increased divergence in the computed displacements after 250-300 ms.

CONCLUSIONS AND RECOMMENDATIONS

The analyses of the tests show that the new sensor and photogrammetry system compared very well with the old nine accelerometer array and the direct photographic measurement of displacement. The new and old angular kinematics and linear accelerations show excellent agreement. However, the new linear velocities and displacements match the photodata velocities and displacements more closely than do the old ones.

Further improvements in the computation of linear displacements are planned. These include: 1) filtering the derived angular accelerations; 2) properly weighting the new least-squares algorithm for obtaining linear accelerations using accelerometer calibration data and 3) refining the numerical integration procedure.

In addition, we are planning improvements in sensor performance. For example, we are currently implementing an improved calibration procedure[2]. Possibly more important, the dynamic range of the ATA sensor (±1600 rad/s) is an order of magnitude more than necessary. All experiments yielded angular velocities below 100 rad/s, which is in the bottom 6% of the dynamic range. A different re-scaled sensor should improve the new system performance.

We are satisfied that the new system performs as well or better than the old system. This confirms the value of the new system as a simpler, more accurate and portable replacement for the old one.

ACKNOWLEDGEMENTS

There are many people whose efforts made this report possible and whom we would like to thank. Mr. Jim Lambert and Mr. Ronnie Wilson of the Mathematical Sciences Division put forth tireless efforts in completing required scientific programming and computing tasks. Ms. Barbara Bishop and Ms. Dorothy Francis of the Data Systems Division, respectively, processed the test data through the old and new analysis systems, and digitized and processed the new 35 mm photodata. Mr. Bill Campos of Pentastar Support Services Inc., photo-digitized the high-speed film. Finally, Ms. June Gordon of the Research Department skillfully produced the final camera ready manuscript.

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[2] A front-surface mirror is mounted on an angular shaker with the reflective surface aligned with the spin axis. A beam from a laser equipped with focusing optics is bounced off the mirror into a screen located a distance away from the shaker. As the shaker is driven sinusoidally at a discrete frequency, a line is "painted" on the screen and, if the length of the line, the distance from the mirror to screen and the driving frequency are known, the angular velocity of the shaker can be readily computed. The advantages of this method are: a) there is no comparison to another sensor required, b) the measurements are made at the displacement level and harmonic distortion is not an issue, and c) the measurement is as close to absolute as possible. Precise knowledge of the frequency of the driving oscillator is all that is needed. If one performs these measurements at a number of discrete frequencies, the sensitivity of the sensor can be determined throughout the operating frequency range.

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Human Factors Causes and Management Strategies in US Air Force F-16 Mishaps 1984-Present

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1. SUMMARY

The F-16 was introduced into the US Air Force in 1975 as the YF-16. It began significant operational employment in the early 1980's. For this paper statistics reflect mishaps since 1984, an arbitrary starting point reflecting mature operational F-16 employment as the venerable F-4 was being phased into retirement.

A review of all F-16 Class "A" mishaps (i.e. loss of aircraft, life, or damage exceeding $1 million) from January 1984 through the end of March 1992 is presented. These mishaps are first listed within traditional causal categories. The mishaps where operator factor was cited are then recategorized into an expanded umbrella framework reflecting operationally meaningful subsets of situational awareness (SA). This SA framework more clearly demonstrates the role and importance of pilot attention and broader awareness in mishap avoidance. A program developed by Tactical Air Command, United States Air Force, to improve pilot attention and awareness is then discussed.

2. MISHAP EPIDEMIOLOGY

There have been 120 Class A mishaps in the F-16 from 1984 to the present. Fifty mishaps have been attributed to system or component failures (mostly engine failures) or maintenance errors. Sixty five mishaps have been attributed to operator factor, while five mishaps have been due to natural causes [bird and lightning strikes]. There have been 42 fatalities associated with these 120 mishaps; all 42 have occurred where operator cause was cited.

Of the 65 mishaps where operator/pilot factor was deemed causal, most authors or Air Force agencies have classified them into traditional categories as shown in Table 1.

The Loss of Situational Awareness (LSA) and Spatial Disorientation (SDO) mishaps are often difficult to differentiate. In all LSA mishaps there certainly has been secondary loss of spatial awareness with respect to the earth's surface. Similarly, in all of the SDO mishaps there certainly has been loss of attitude situational awareness. For the 28 combined LSA and SDO mishaps, six have occurred in day visual flight conditions with a distinct horizon; 14 occurred in a degraded visual environment (either night or weather), but an unusual attitude was not encountered; and in eight an unusual attitude was encountered in a degraded visual environment. Therefore, some crossover and mixing of causality exists within these two traditional causal categories.

Table 1. F-16 Class A Mishaps, 1984 to 1992, with Operator Cause Cited.

Traditional Category	Number of Mishaps	Number of Fatalities
G Loss of Consciousness (G-LOC)	6	6
Loss of Situational Awareness (LSA)	14	12
Spatial Disorientation (SDO)	14	12
Loss of Control (LOC)	6	0
Midair Collision	12	9
Takeoff or Landing Phase	6	0
Miscellaneous	7	3
	65	42

2.1 Expanded Concept of Mishap Causality

The current concept of situational awareness lacks operational reality and often is narrow in focus, typically highlighting "Top Gun" air fighting skills while ignoring other aspects of global situational awareness. A "Situational Awareness Umbrella" nicknamed SABRELLA was developed as an analogy to depict a more complete situational awareness (SA) model from an operational perspective. The SABRELLA analogy as it displays this SA concept is shown in Figure 1.

The detractors of SA are shown as "raining down" onto the SABRELLA, trying to "ruin your day" by

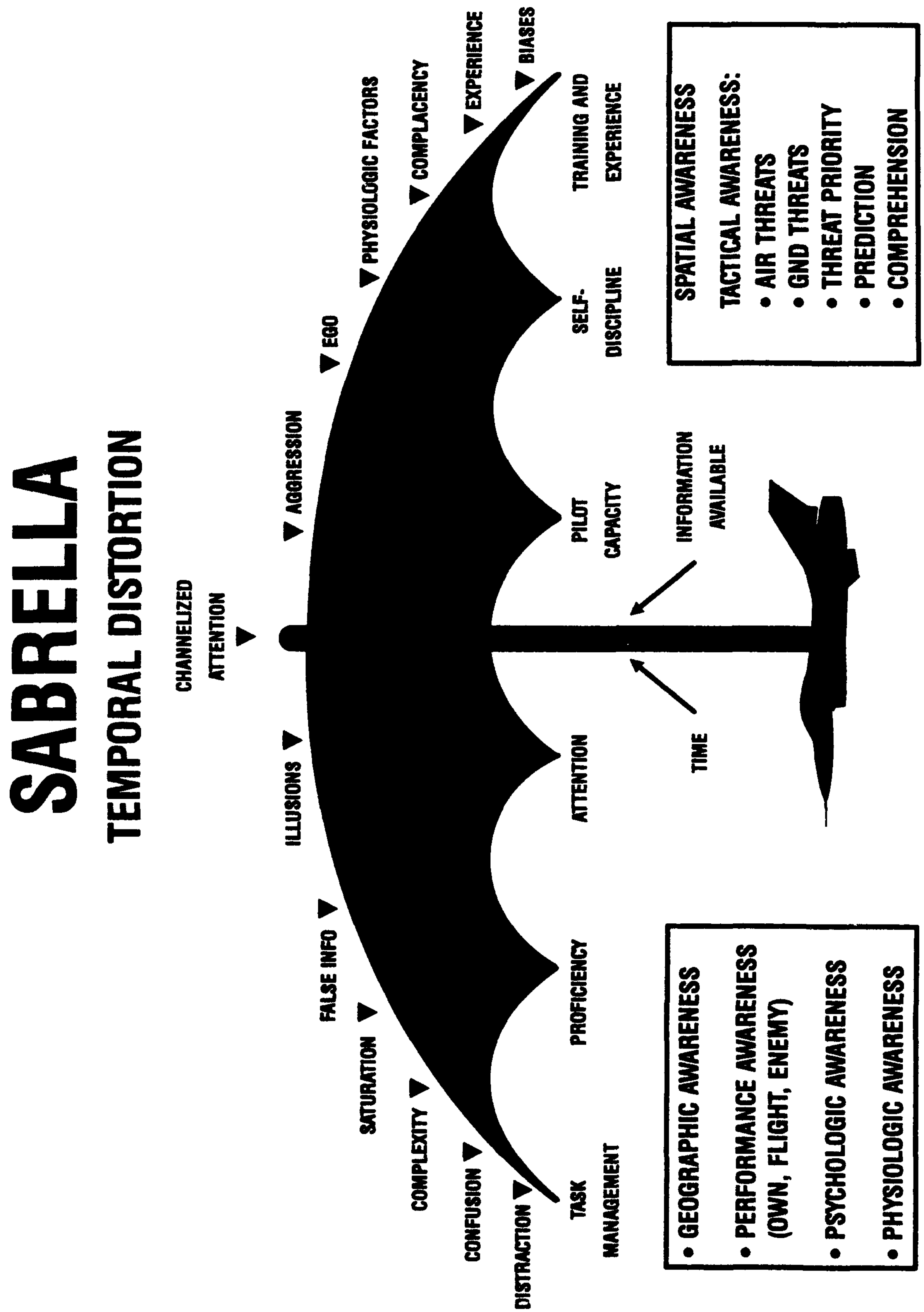
SABRELLA
TEMPORAL DISTORTION
CHANNELIZED ATTENTION
DISTRACTION
CONFUSION
COMPLEXITY
SATURATION
FALSE INFO
ILLUSIONS
AGGRESSION
EGO
PHYSIOLOGIC FACTORS
COMPLACENCY
EXPERIENCE
BIASES
TASK MANAGEMENT
PROFICIENCY
ATTENTION
PILOT CAPACITY
SELF-DISCIPLINE
TRAINING AND EXPERIENCE
TIME
INFORMATION AVAILABLE
• GEOGRAPHIC AWARENESS
• PERFORMANCE AWARENESS (OWN, FLIGHT, ENEMY)
• PSYCHOLOGIC AWARENESS
• PHYSIOLOGIC AWARENESS
SPATIAL AWARENESS
TACTICAL AWARENESS:
• AIR THREATS
• GND THREATS
• THREAT PRIORITY
• PREDICTION
• COMPREHENSION
SG 2651

Figure 1.

degrading SA. These are traps or predisposing factors that lead to aircrew error. These detractors are constantly a potential nuisance during many phases of flight on most daily operational F-16 sorties.

The supporters of SA are shown as the struts in the frame of the SABRELLA, as they try to retain awareness by countering the detracting influences. The "supporters" of SA include management of task priorities, flying proficiency and currency, attention, pilot capacity, self-discipline, training, and experience. The "detractors" include confusion, distraction, task saturation and complexity, channelized attention, illusions, false information, ego and aggression, physiological detractors, complacency, experience, biases, and TEMPORAL DISTORTION.

The potential augmentation of SA is shown blending into the handle of the SABRELLA. These are post-takeoff variables that can add stability to or enhance the SA framework in a fluid environment: time and additional information that becomes available. Under the SABRELLA is depicted the aircraft being flown operationally, and those "subsets" of SA that your SABRELLA is trying to preserve from the "rain of detractors".

Six situational awareness subsets are shown in Figure 1:

- Geographic Awareness
- Performance (aircraft) Awareness
- Psychologic Awareness
- Physiologic Awareness
- Spatial Awareness
- Tactical Awareness

These subsets are not meant to be an exhaustive listing of all of the elements of global situational awareness. However, they describe most operational situations, and at many times are paired or grouped with each other in a complex way. It may be difficult to determine which subset is the primary cause in a mishap scenario.

Geographic awareness describes position of the aircraft in latitude/longitude over the earth's surface. Performance awareness refers to aircraft (not person), and includes one's own aircraft as well as the performance of the enemy's or wingman's aircraft. Psychologic awareness describes the pilot's self-assessment of his current psychological state (mood, anger, ego-control, embarassment, vigilance, motivation,...). Physiologic awareness describes the pilot's assessment of his physiological condition (fatigue, illness, fitness, G tolerance, thermal burden). Spatial awareness describes attitude orientation of the aircraft with respect to the surface of the earth. Tactical awareness is the most complex in the fighter aviation environment, and includes multiple variables. Other air threats and own wingman position, ground threats to the aircraft, mission scenario, navigation requirements, threat priorities, complex information processing, comprehension of the tactical situation, and predictive capability are just some of the many variables presented to the pilot in the tactical environment.

In summary, the SABRELLA analogy depicts the elements that may degrade SA, elements that provide fundamental SA, elements that may enhance SA once airborne, and components of SA that the pilot is trying to preserve. Maximal preservation of SA ultimately protects the pilot and his weapon system and better enables the employment of that weapon system, both in peacetime and in combat.

2.2 Recategorization of F-16 Class A Mishaps

Using the six subsets of SA depicted beneath the SABRELLA analog, the 65 operator-related mishaps can be reclassified. Analysis of each mishap allows a description of the subset(s) of SA that were degraded during the mishap scenario. This recategorization is shown below in Table 2.

Table 2. Recategorization of F-16 Class A Mishaps into Subsets of Degraded Situational Awareness (SA).

Category	Number Mishaps	Number SA Degraded	Subset SA Degraded
G-LOC	6	6	Phy, Per, Psy
LSA/SDO	28	28	Tac, Spa
LOC	6	6	Spa, Per, Tac, Psy
MidAir	12	9	Tac, Per, Psy
Takeoff/ Landing	6	3	Spa, Per
Miscel- laneous	7	4	Tac, Geo, Psy, Per
	65	56 (86%)	

Phy= Physiologic Spa= Spatial
Psy= Psychologic Tac= Tactical
Geo= Geographic Per= Performance

The following discussion presents an example of the degradation of a situational awareness subset within each traditional causal mishap category.

G Loss of Consciousness (G-LOC): In all of these mishap scenarios failure to monitor physiologic awareness has been directly causal. If the pilot monitors G onset and duration in the context of physiologic capability, G-LOC will not occur. Aircraft performance is also a factor as it determines high G capability, and psychologic state has been a contributor in some mishaps where excess motivation to succeed or attempting to recover from a previous embarassing engagement were factors in the mishap. Suboptimal psychological states degrade the pilot's ability to maintain awareness within the other subsets.

Loss of SA/Spatial Disorientation (LSA/SDO): In most of these mishaps degraded tactical awareness has been instrumental. Task saturation, channelized attention, distraction or task misprioritization leads to degraded tactical awareness and thence to potential loss of spatial awareness with resultant collision with the ground. In some of the scenarios loss of spatial awareness is the only probable factor as no tactical scenario was operative.

Loss of Control (LOC): In all of these mishaps loss of spatial and performance awareness are directly causal. Assessment of aircraft attitude in relation to airspeed is critical if loss of control is to be avoided. Often tactical awareness is also degraded, as "nose high and slow airspeed" are generally tactically unsound maneuvers. Psychologic awareness has been a factor as well in some of these mishaps, as a pilot in an effort to gain positional advantage disregards aircraft attitude and performance.

MidAirs: These are complex scenarios, but in many of the mishaps (75%) loss of tactical and performance awareness have been operative as well as loss of psychological awareness. Similarly to loss of control mishaps, desire to achieve a fighting advantage precludes appropriate assessment of the tactical situation or aircraft performance and flight vector.

Takeoff and Landing: About half of these mishaps have involved degraded spatial awareness (sink rate not perceived) and/or degraded performance awareness (failure to assess available aircraft performance in the presence of a high sink rate).

Miscellaneous: The best example within this group is fuel starvation where degradation of SA may occur within several subsets: poor tactical awareness of fuel state during the air to air dogfight; poor geographic awareness of where the recovery bases are located; poor psychological awareness as a pilot fights the opponent to a low fuel state; or complacency during a navigation flight with failure to perform regular cross-checks of fuel quantity or status.

When all 65 mishaps are analyzed a "primary causal subset of degraded SA" can be assigned to 56 (86%). The results are shown in Table 3.

Table 3. F-16 Class A Mishaps with Degraded Situational Awareness (SA).

Primary Subset of SA Degraded	Number of Class A Mishaps
Tactical Awareness	27
Performance Awareness	10
Spatial Awareness	8
Physiologic Awareness	6
Psychologic Awareness	5
Geographic Awareness	0

3. DISCUSSION

56 of 65 Class A F-16 mishaps can be placed within the various subsets of a more global perspective of operational situational awareness. This categorization reflects how degradation of any of these SA subsets can contribute to degradation of other subsets and to a sequence of causal events that may culminate in an aircraft accident. Improving pilot attention and awareness skills should break this sequence of events through optimization of SA and reduce mishap likelihood.

3.1 Aircrew Attention and Awareness Management Program

In an effort to reduce Class A mishaps, the US Air Force's tactical air forces and Tactical Air Command (TAC) have developed a program whose strategy is aimed at enhanced aircrew attention skills and situational awareness. This program is called "Aircrew Attention and Awareness Management Program" (AAAMP) which is gradually being phased into all levels of training in TAC. The curriculum is being developed by a team of aerospace physiologists, aerospace medicine specialists, and experienced USAF pilots.

The program is planned for phasic implementation, with the first phase being presented at basic fighter training at Holloman AFB, NM; the second phase will be presented to students at fighter training units throughout the command; the third phase will target the instructors at these training units; and the final phase will be presented at operational units. Phases 1 and 2 have already begun. Part One of the curriculum is composed of three hours of basic physiology which addresses perception, memory, information integration and processing, decision and response selection, task execution and attention problems. Subsequent parts of the curriculum are mission-specific, developed for each aircraft type and mission type (air-to-air, air-to-ground, night interdiction, etc).

A mission planning model is a key element of the curriculum, which provides a framework for analysis of potential events for the entire mission from takeoff to landing to include the environment, the aircraft, the aircrew member, the situation, and the mission scenario. High probability human performance concerns are analyzed and a response plan is developed for each concern within the mission model. Mission segments where high task loading is likely come under careful scrutiny; task pacing may be rehearsed, and a plan to deal with loss of SA is developed.

The goal of the program is improved attention skills, which should be reflected in increased global situational awareness and improved predictive skills. Time sharing skills should improve, and will include time for assessment of physiological and psychological conditions as well as tactical and spatial concerns. Critical versus non-critical tasks are pre-identified before takeoff; task execution will be dependent upon attention, awareness and time available. The overall impact of a successful training program will be heightened awareness skills with a reduction in aircrew error rate. The main benefactor will be improved aircrew performance for 99,999 of 100,000 flying hours; the benefit to a broken causal mishap sequence will occur in that one flying hour per 100,000 where error has a catastrophic outcome.

The AAAMP has admitted limitations. Pilot knowledge, experience, proficiency, and scenario familiarity are not well taught in the classroom. However, a dedicated attention skills training program should hasten knowledge acquisition, enrich available flying experiences, and improve proficiency that is otherwise gained in a more haphazard fashion through trial and error or "near-miss" experiences.

Future expansion to incorporate simulators for cockpit attention and awareness skills training is not presently built into the program. Realistic high fidelity mission scenarios could be developed to assess and refine pilot attention skills, improve task execution, and identify deficiencies in cockpit pacing.

4. CONCLUSION

Traditional categorization of mishaps where operator factor was cited do not reflect the human performance issues that were instrumental in the sequence of events. The SABRELLA model depicts an operational perspective of these human performance issues (detractors, supporters, augmentors) and the subsets of situational awareness that the pilot wishes to preserve. In a great majority (86%) of F-16 Class A mishaps with operator factor cited, **degradation of some aspect of situational awareness is causal.** An approach to investigate these mishaps and a program to reduce their frequency must focus on the root causes of pilot performance degradation. The discussion presented here focuses on attention and awareness skills that if improved should enhance pilot performance and reduce mishap tendencies. All of the G-LOC and loss of control mishaps could have been avoided with fundamental enhancement of physiological, aircraft performance and psychological awareness. The "SA/SDO" and midair mishaps are more complex, but would also benefit from fairly modest enhancement of tactical awareness skills and task execution skills.

The Tactical Air Command's AAAMP program is only one of several attention and awareness management concepts currently being implemented around the globe. The airlines have a similar program that focuses largely on task management for multiplace cockpits without tactical considerations. Hopefully over the next few years these programs and concepts will mature and provide the pilot with improved cockpit attention and awareness skills that will reflect itself in a reduced mishap rate.

F - 16 ACCIDENTS : THE NORWEGIAN EXPERIENCE

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1 INTRODUCTION

Investigation reports from F-16 mishaps in the Royal Norwegian Air Force have been studied.

In order to evaluate and improve the human factor information contained in the written records of F-16 mishaps, we have examined all information available in the Royal Norwegian Air Force for a ten year period, 1981 to 1990.

2 F-16 OPERATIONS IN NORWAY

2.1 Environment

Norway is a long and narrow country. The northern part is not much more than a coastline, behind which mountains rise to an altitude of approximately 6000 feet. The fjords cut deep inland.

Neighbouring countries are Sweden, Finland and Russia.

The climate is rough with cold winters and strong winds. For most of the year, operations are frequently restricted due to fog, white-out conditions, powerful crosswinds and slippery runways. Weather conditions may change rapidly.

Power lines represent a special hazard, even at high altitudes.

2.2 Mission

The RNoAF (Royal Norwegian Air Force) operates the F-16 in air defence, and recently, also in the anti-sea invasion role.

2.3 Total hours flown

For the RNoAF, this amounts to somewhere between 100 000 and 150 000 hours.

3 MISHAP DATA

3.1 Lost aircraft

Until March 1992, the RNoAF has lost a total of 13 F-16s. Of these, 12 were lost in flight related mishaps, including 1 bird strike, 2 engine failure and 9 human factor.

Of the 9 aircraft lost in human factor related mishaps, 3 were mid-air collisions, 4 controlled flight into terrain, 1 G-induced loss of consciousness and 1 other.

Of the 3 mishaps not related to human factors, none were fatal.

Of the 9 mishaps related to human factors, 6 were fatal.

3.2 Comparative mishap data

The loss rate per 100 000 flight hours by the end of 1991, amounts to 9,2 for Norway, 10,8 for the European Air Forces (Belgium, the Netherlands, Denmark and Norway), and 5,0 for the USAF.

However, when passing 100 000 flight hours, Norway had a loss rate of 11,5 , the same as the USAF, whereas the average for the European Air Forces was 20.

4 METHOD

Investigation reports from RNoAF F-16 mishaps for a ten year period, 1981 to 1990, have been reviewed.

Initially, 33 reports were obtained. Of these, 13 were excluded because of lack of human factor data.

The material thus consists of 20 reports; 6 from investigation officers and 14 from full boards of investigation.

Reports available include fatal and non-fatal, major and minor mishaps, as opposed to the figures of aircraft losses above.

The human factor data in each report have been evaluated. The following questions have been asked:

- What were the human factor investigators asked to look for?
- What methods ("tools") were available to them?
- What was obtained from the investigation?
- What recommendations concerning human factors were made?

5 RESULTS

5.1 Evaluation of results

This limited material does not permit a statistical analysis.

In the following, findings in the reports are presented and evaluated according to the experience and personal views of the authors.

5.2 What were the human factor investigators asked to look for ?

Two kinds of questions come in this category: Firstly, questions as to the <u>cause</u> of the accident. Secondly, <u>other</u> important human factor considerations.

The most common questions regarding human factor <u>causes</u> were:

- Can any source of lack of concentration be detected?
- Is there any evidence of pre-existing illness?
- Was there a probability for loss of consciousness, medical or physiological?
- May any reason for reduced visual performance be determined?

<u>Other</u> typical human factor questions were:

- How can the pilot's injury be explained?
- Why did the pilot lose his helmet?
- Why did not the pilot try to eject?

5.3 What methods ("tools") were available?

The interview is, of course, central in human factor investigation. Interviewed persons range from mishap pilot (if alive) to relatives, mates, unit commanders, eye witnesses etc.

Other classical investigation methods include physical examination, blood and urine sampling and autopsy - when applicable.

Other sources of information are:

- Taped communication
- Video tapes
- Reports on weather conditions
- Pilot manuals, check lists, maps and other published material
- Simulator set-up of the flown mission
- Actual reflying of the mission
- Seat Data Recorder readout

5.4 Answers given by investigators of human factors

No mishaps have been proven to be caused by pre-existing disease, neither have alcohol, drugs nor self - medication been factors.

Typical answers given by the investigators were:

- Loss of Situational Awareness
- Channelized attention
- Spatial disorientation
- "Got-it-done-itis"
- Overconfidence
- Lack of continuation in flying
- Lack of sleep

Among these, the most frequent were: Lack of continuation in flying, got-it-done-itis and channelized attention.

5.5 Recommendations concerning human factors, regarding cause of mishap

Typical recommendations were:

- Better maps and briefing guides, better briefings
- More consistent enforcement of Rules Of Engagement
- Better respect for Low Flying Regulations
- More effective anti-G systems, compulsory centrifuge training, G-warm-up turns, more aeromedical education
- Further stressing of the hazards of changes in normal procedures, when transiting to new aircraft
- Change in regulations to cover rules for continuity in night flying

5.6 Other human factor recommendations

These refer almost exclusively to better life support equipment and better training for its use.

6 RECOMMENDATIONS FOR IMPROVED HUMAN FACTOR INVESTIGATION

6.1 The flight safety potential.

In the RNoAF, the question of whether mishap investigation is to be performed by an investigation officer, or by a full board of investigation, is essentially determined by the cost of damage repair. The authors feel that the flight safety potential of the mishap would be a better determinator.

6.2 Reconstruction

Reconstruction, that is, piece-to-piece reconstruction of the events leading up to the mishap, always proves extremely valuable. Some of the best tools are simulator set-up and actually reflying the mission.

6.3 The video tape

The video tape in the F-16 is too short to record a whole mission. Therefore, the camera is switched on and off to cover the more interesting parts of the mission. Unfortunately, the camera all too often has not been turned on at all, or has been turned off just prior to the mishap. Therefore, potentially very valuable information is never recorded. From an investigation point of view, the camera system in the F-16 should be modified to permit recording of an ordinary mission from start of the engine to shut-down.

6.4 The mechanism of error

Human factor investigators search meticulously to document blood analyses, meal habits and sleep patterns. Reconstruction and interpretation of more intricate mechanisms of error (for example, what makes a pilot choose his landing gear handle up when what he should have done, was to give full throttle) is often less satisfactory.

6.5 Sociopsychological considerations

Sociopsychological considerations are more often than not, poorly documented in the reports. The information provided by full boards of investigation including a flight surgeon, is only marginally better than that obtained by investigation officers. Better standardization in this area of documentation, is highly desirable.

6.6 The forgotten mechanic

Our interest in human factors and errors seems by definition to stop at the aircrew. Whenever a technician or other ground personnel exercises poor judgement or makes a faulty decision, we do not perform a proper human factor investigation, just label any finding as "maintenance error" or similar. Maybe this is a new area of interest for our human factor concerns, both in mishap investigation and in prevention.

LES ACCIDENTS F-16 DE CATEGORIE A A LA FORCE AERIENNE BELGE

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SUMMARY

The Belgian Air Forces are flying on F-16 since 1979; a review of all the class A mishaps is realized.
This global study point out a particular human factor that could not be find in a single analysis of each mishap.

RESUME

La Force Aérienne Belge utilise le F-16 depuis 1979; une revue globale de tous les accidents de catégorie A a été réalisée.
Cette étude fait apparaître un facteur humain particulier qui ne pouvait être mis en évidence par l'analyse isolée de chacun des accidents.

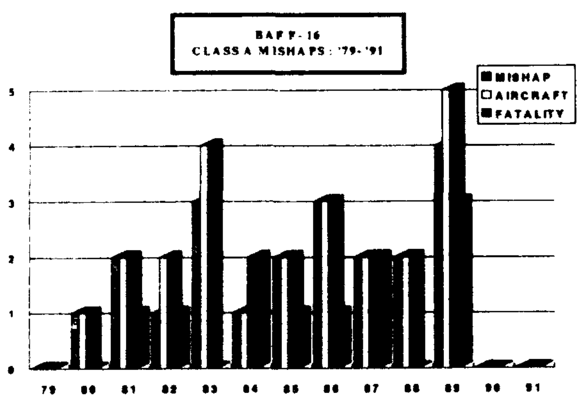
INTRODUCTION

L'objet de cet exposé est de vous présenter une synthèse des accidents F-16 de catégorie A survenus à la Force Aérienne Belge; je pense posséder une bonne connaissance des dossiers, ayant été conseiller médical du Service d'Enquête de 1975 à 1990.
Les données chiffrées qui vont vous être communiquées constituent les statistiques officielles de mon pays tandis que le commentaire qui les accompagne comporte des considérations qui ne représentent pas nécessairement le point de vue officiel de la Force Aérienne.

CATEGORIE A

En Belgique, un accident est catégorisé A quand l'avion est perdu - qu'il soit détruit, disparu, inaccessible ou encore irréparable économiquement parlant - et/ou bien quand une personne, membre d'équipage ou non, y trouve la mort.

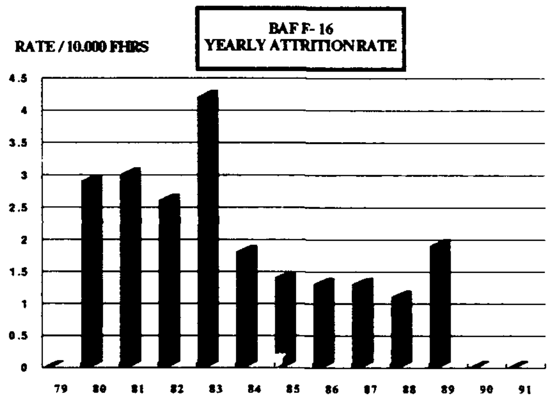
BILAN GLOBAL DES PERTES



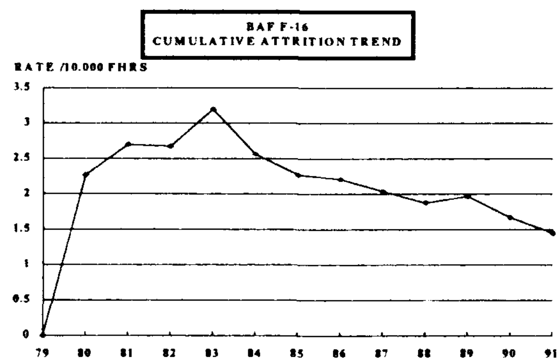
La Force Aérienne Belge a connu 21 accidents F-16 de catégorie A entre 1979, année de réception des premiers avions de ce type, et fin 19:1.
Ces accidents ont entraîné la perte de 24 F-16; ils ont causé la mort de dix pilotes et d'un mécanicien.

TAUX D'ATTRITION

Au 31 décembre 1991, les F-16 belges qui sont repartis en trois Wings à deux Escadrilles chacun, avaient volé un total de 165.000 heures.
Le taux d'attrition qui exprime le nombre d'avions détruits par 10.000 heures de vol, permet certaines comparaisons.



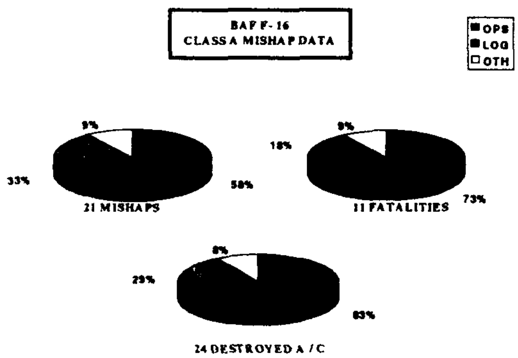
Ainsi le taux annuel d'attrition de la Force Aérienne Belge a été supérieur à 2 de 1980 à 1983, s'est situé entre 1 et 2 de 1984 à 1989 pour devenir inférieur à 1 en 1990 et 1991.



Le taux cumulatif d'attrition qui, chaque année, intègre les résultats de toutes les années précédentes, donne une courbe de tendance: la courbe belge est haut située et, pour parler clairement, avec un taux cumulatif de 1.4, la Belgique est encore loin, fin 1991, des bons résultats publiés par d'autres pays utilisateurs du F-16. Il faut cependant souligner que ce type de comparaison doit être pris avec circonspection, les particularités des missions et les conditions d'environnement n'étant pas superposables d'un pays à l'autre.

CAUSES DES ACCIDENTS

Les causes des accidents aériens sont classiquement divisées en trois groupes:
- les causes opérationnelles où c'est essentiellement l'équipage qui est impliqué dans la genèse de l'accident.
- les causes techniques où l'avion, sa maintenance ou ses systèmes sont prioritairement à l'origine du sinistre.
- et les autres causes, ce groupe réunissant les accidents où ni les opérations ni la technique ne sont concernées de manière primordiale.



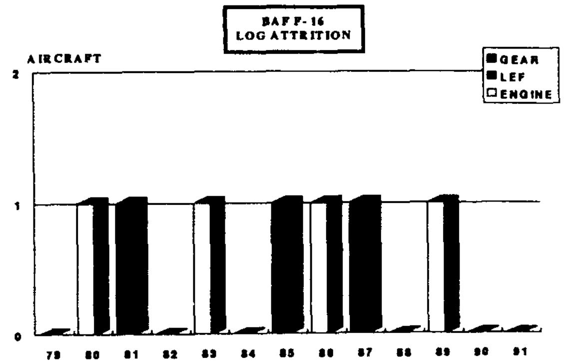
La répartition des accidents F-16 de la Force Aérienne Belge, suivant ce schéma, met en évidence que les accidents de cause opérationnelle représentent une grosse moitié des sinistres, qu'ils sont à l'origine des deux tiers des pertes de F-16 et qu'ils ont causé les trois quarts des décès.

LES CAUSES DIVERSES

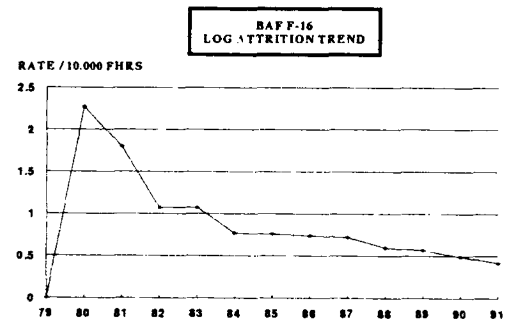
Voyons de plus près les trois groupes d'accidents, en commençant par les accidents non apparentés aux opérations ou à l'état de l'avion.
La Belgique en a connu deux:
- Le premier est une collision avec un oiseau au décollage: toutes les nations sont bien conscientes de l'importance de la lutte contre le péril aviaire.
- Le second accident est très particulier: un mécanicien s'est emparé d'un F-16 qui s'est écrasé peu après le décollage.

LES CAUSES TECHNIQUES

Les accidents de cause technique, au nombre de sept, se répartissent comme suit:
- 04 pannes de moteur en 1980, 83, 86 et 89.
- 02 bris de commande des volets de bord d'attaque, ces accidents ayant été mortels.
- et 01 panne hydraulique de train d'atterrissage.



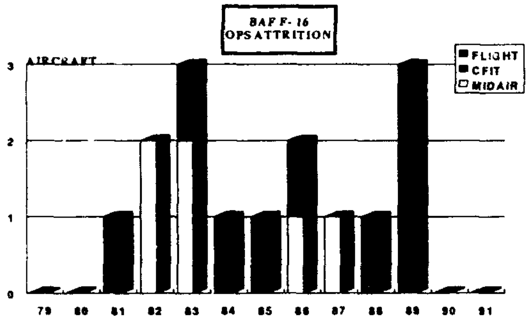
Avec ces pertes, surtout élevées pendant les toutes premières années d'utilisation du F-16, le taux cumulatif d'attrition technique se situe actuellement au niveau de 0.4 pertes d'avion par 10.000 heures de vol.



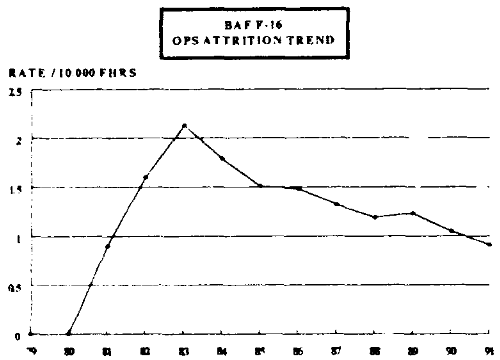
LES CAUSES OPERATIONNELLES

L'attrition d'origine opérationnelle a été, elle, importante de 1981 à 1989.
En effet la perte de quinze F-16 est attribuée à des causes opérationnelles qui se répartissent comme suit:
- 04 pertes d'avions en relation avec la mission opérationnelle
- 05 avions perdus dans ce qu'il est convenu d'appeler des vols contrôlés jusque dans le terrain
- et 06 avions détruits suite à des collisions en vol.
Détaillons un peu cela:
- les 04 accidents en rapport direct avec le vol se subdivisent comme suit:
un arrêt moteur induit par le pilote, une éjection sur désorientation spatiale, une panne moteur consécutive à un atterrissage trop brutal et une perte de contrôle du fait du pilote.
- Les 05 vols contrôlés jusque dans le terrain se sont soldés par le décès des cinq pilotes. Deux sont morts dans la collision de leurs avions avec le sol au cours d'une même approche dans de mauvaises conditions météorologiques; les trois autres se sont écrasés suite à des changements non intentionnels du vecteur de leur avion, consécutifs à la perte du jugement correct de la situation.
- quand aux 06 avions détruits lors des collisions en vol, quatre F-16 l'ont été dans deux collisions aériennes en combat simulé, l'une en 1982 et l'autre en 1983, un F-16 a été perdu lors d'une collision entre avions de deux formations diffé-

rentes et un autre suite à un manque de discipline en vol.



Avec un tel nombre d'accidents, le taux cumulatif des pertes opérationnelles ne peut qu'être élevé: il s'établit actuellement à 0.9 F-16 par 10.000 heures de vol.



En 1989, ce taux se situait à 1.2 et la courbe avait pris une allure ascendante, ce qui n'était plus arrivé depuis 1983! Une analyse des dossiers a permis alors de mettre en évidence un problème particulier, propre à une seule Escadrille, à savoir une série d'accidents, entre 1985 et 1989, caractérisés par l'intrication de manquements en matière de respect des règles ou instructions (*réaction non idéale du pilote, non respect des limitations de vol*), en matière de prudence (manoeuvre dangereuse, non utilisation de tous les moyens disponibles pour assurer la sécurité en vol) et/ou en matière de supervision (mission dont la difficulté excédait les capacités d'un jeune pilote, absence de prise en considération d'un manque d'entraînement récent).
Des mesures ont été prises pour modifier la mentalité au sein de cette unité, avec succès semble-t-il, puisque, grâce aux années 1990 et 1991 sans aucun accident, la Force Aérienne Belge rejoint progressivement le taux cumulatif d'attrition des autres pays européens utilisateurs du F-16.

COMMENTAIRES

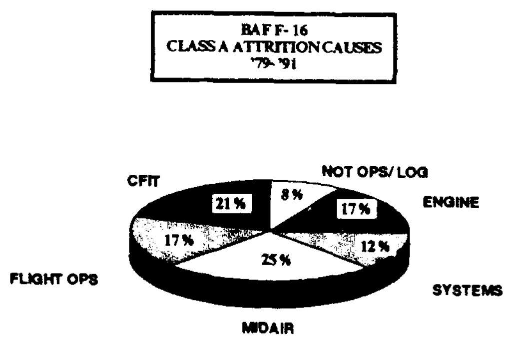
Ce bilan, *sans complaisance* puisqu'il porte sur toutes les pertes d'avion durant toutes les années d'utilisation du F-16, mérite quelques commentaires:

- Primo, le fait d'avoir été la première nation en Europe à utiliser le F-16 explique, au moins partiellement, les pertes élevées des premières années, qu'elles soient opérationnelles ou techniques.
Ainsi les deux collisions en combat simulé trouvent-elles leur origine dans les changements non prévisibles de trajectoires rendus possibles par l'hypermaniabilité des F-16 : ces performances étaient absolument nouvelles à l'époque.
De même c'est en Belgique, en 1981, que le bris d'une commande de volets a été constaté pour la première fois.
La perte de ces cinq avions explique le taux élevé d'attrition des premières années qui se répercute évidemment encore dans le taux cumulatif d'aujourd'hui.
- Secundo, après avoir constaté à plusieurs reprises que des facteurs humains d'accidents pouvaient se trouver bien loin du pilote et de l'avion, la Force Aérienne Belge a réussi à convaincre son personnel que *la sécurité aérienne était vraiment l'affaire de tous*.
- Tertio, et c'est le point essentiel, il n'était pas évident au départ d'identifier une mentalité comme cause commune à plusieurs accidents, par ailleurs très différents.

RECOMMANDATION

De rétrospectif, ce type d'analyse doit maintenant devenir prospectif en considérant les accidents de catégorie B et C comme un baromètre de la situation; en effet la différence entre un accident mineur et un accident majeur réside uniquement dans les conséquences, la cause pouvant en être la même.

CONCLUSION



En conclusion, il s'avère que bien peu d'accidents sont purement fortuits; c'est dire que le hasard et la chance n'ont pas de place en matière de sécurité aérienne. Bien sûr une aviation sans accident n'existera jamais puisque le vol n'est pas sans risques, toutefois il convient de n'accepter que les risques justifiés par l'accomplissement de la mission, seule raison d'être d'une Force Aérienne.

ACCIDENTS AERIENS DANS L'ARMEE DE L'AIR FRANCAISE (1977-1990)

Influence des aéronefs de la nouvelle génération.

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RESUME

Le bilan des accidents aériens dans l'Armée de l'Air Française a porté sur la période 1977 - 1990. Au cours de cette période, des avions de combat de nouvelle génération ont été mis en service sans qu'il ait été observé de variation importante du nombre d'accidents aériens bien que le taux d'accident pour 10 000 heures de vol paraisse plus élevé sur les aéronefs nouveaux. Le facteur humain reste la cause principale des accidents aériens dans la catégorie combat mais semble être moins fréquemment impliqué avec les aéronefs de nouvelle génération. La mortalité au cours des accidents de combat tendrait à décroître régulièrement depuis 1987.

L'amélioration de la sécurité des vols revêt un caractère particulièrement important en aéronautique. *L'Etat Major de l'Armée de l'Air* accorde une importance capitale aux enquêtes sur les accidents aériens militaires dans le but de déterminer leurs causes et de minimiser leur fréquence grâce aux enseignements tirés de ces enquêtes.

Il faut entendre par accident aérien, selon la définition de l'Instruction IV.25 de l'Armée de l'Air qui reprend celle de l'OACI, tout accident survenu en vol, entre le lâcher des freins au décollage et le dégagement normal de la piste à l'atterrissage, ayant entraîné la destruction de l'aéronef et/ou la mort d'un des membres de l'équipage.

Ce travail a été effectué sur la période 1977-1990. Il complète un travail antérieur (OSSARD et MARTEL 1990) qui avait souligné la prédominance des accidents aériens dans l'aviation de combat par rapport aux autres catégories opérationnelles. Au cours de la dernière décennie ont été mis en service des avions dits de "nouvelle génération" qui apportent des procédures de pilotage différentes de celles des aéronefs antérieurs. Grâce à l'utilisation des calculateurs de bord, c'est l'énergie des appareils qui est pilotée au cours de leurs évolutions. De plus, les systèmes de visualisation en tête haute occupent une place importante dans les tâches de pilotage. En outre, l'utilisation de commandes de vol électriques sur Mirage 2000 a radicalement modifié les conceptions classiques de pilotage.

Il était donc particulièrement important d'évaluer l'influence de cette nouvelle génération d'avions de combat sur les accidents aériens.

La mise en service de ces aéronefs nouveaux remonte à 1982 pour le Mirage F1CR et le Mirage 2000C et B, et 1986 pour le Mirage 2000N. Il faut toutefois tenir compte du fait qu'il s'écoule en général deux années entre la mise en service d'un appareil nouveau et le début de son utilisation avec un volume d'activité opérationnel. De plus, ce volume d'activité augmente progressivement sur une période de trois ans avant d'atteindre le niveau opérationnel optimal.

BILAN EPIDEMIOLOGIQUE DES ACCIDENTS AERIENS MILITAIRES DE 1977 A 1990.

Les principaux facteurs permettant d'évaluer le bilan épidémiologique des accidents aériens sont leur fréquence, leurs causes et leurs conséquences au niveau des pertes humaines. Nous aborderons globalement chacun de ces trois aspects sur la période 1977-1990 puis nous distinguerons les périodes antérieure et postérieure à l'année 1982 au cours de laquelle ont été mis en service les premiers aéronefs de nouvelle génération.

1. Fréquence des accidents aériens :

1.1. Fréquence relative :

De 1977 à 1990 l'Etat-Major de l'Armée de l'Air Française a dénombré 210 accidents aériens pour 5 617 312 heures de vol. Cette activité aérienne se répartissait entre l'aviation de combat pour 36 % , l'aviation d'école (incluant la Patrouille Acrobatique de France) pour 32 % , le transport aérien pour 24 % et l'activité hélicoptères pour 6 % , le reliquat (2 %) concernant des activités diverses telles que les sports aériens et le vol à voile *(Fig. 1.)*. Durant cette période, la proportion d'accidents pour chaque catégorie opérationnelle a été de 72 % pour l'aviation de combat, 20 % pour l'aviation d'école, 2 % pour le transport aérien militaire, 5 % pour l'activité des hélicoptères et 1 % pour le reste de l'activité. Il existe donc, en première analyse, une nette prévalence des accidents dans la catégorie combat avec plus de 2/3 des accidents aériens alors que l'activité aérienne correspondante dépasse légèrement 1/3 de l'activité globale.

Il n'existe pas de différence dans la répartition des accidents aériens par catégories opérationnelles entre les périodes antérieure et postérieure à 1982 (73 % d'accidents de combat et 20 % d'accidents en école de 1977 à 1981 contre 72 et 21 % dans ces catégories respectives après 1982).

Depuis 1982, 130 accidents aériens ont concerné la catégorie combat dont 13 % pour les avions de nouvelle génération. Mais si l'on ne considère que la période d'activité opérationnelle ayant débuté en 1985 pour le Mirage F1CR et le Mirage 2000 B/C et en 1988 pour le Mirage 2000N, 79 accidents aériens ont été recensés dont 21 % pour les aéronefs de nouvelle génération. Durant cette période, l'activité aérienne sur ces appareils représentait 20 % de l'activité de l'aviation de combat ce qui montre un certain parallélisme entre le volume d'activité et la proportion d'accidents avec les avions de nouvelle génération. Le Mirage F1CR a été l'appareil le plus souvent impliqué dans ces accidents. En effet, il a été impliqué dans 53 % des accidents d'aéronefs de nouvelle génération pour une activité opérationnelle qui ne représentait que 39 % de l'activité de ces appareils.

1.2. Taux d'accident :

Pour évaluer la fréquence des accidents aériens de manière comparative d'une année sur l'autre, leur nombre est rapporté au volume de l'activité aérienne. Le taux d'accident représente le nombre d'accidents pour 10 000 heures de vol.

De 1977 à 1990, le taux annuel d'accident (moyenne ± SE), toutes catégories confondues, a fluctué sans tendance nette autour d'un taux de 0.37 ± 0.08 *(Fig. 2.)*. Durant cette période, les taux d'accident (moyenne ± SE) sont les plus élevés pour les catégories combat (0.74 ± 0.20) et école (0.24 ± 0.13). Les taux d'accident de la catégorie combat sont nettement supérieurs au taux général alors que le phénomène inverse est observé pour la catégorie école, exception faite de l'année 1980.

Il n'est pas retrouvé de variation importante du taux moyen d'accident dans la catégorie combat depuis la mise en service des Mirage F1CR et 2000 (0.76 ± 0.19 avant 1982 ; 0.72 ± 0.20 après 1982).

L'évolution des taux d'accident pour chacun de ces aéronefs a été étudiée *(Fig. 3.)*. Pour les aéronefs de nouvelle génération, à l'exception du Mirage 2000B qui n'a été impliqué dans aucun accident jusqu'en 1990, ce taux est nul au cours des premières années de leur mise en service puis se positive ensuite, la latence étant de trois ans pour le Mirage 2000C, 4 ans pour le Mirage 2000N et 5 ans pour le Mirage F1CR. Il n'existe pas de variation homogène de ces taux d'accident depuis la mise en service des avions de combat de la nouvelle génération. Il faut toutefois souligner le fait que les taux d'accidents des aéronefs de la nouvelle génération sont très supérieurs à ceux de la catégorie combat considérée globalement depuis 1982.

2. Causes des accidents aériens :

2.1. Bilan général :

De 1977 à 1990 l'imputabilité des accidents aériens toutes catégories confondues se répartissait de façon suivante : facteur humain 63 %, cause mixte où le facteur humain prenait part 6 %, cause technique 21 %, environnement 5 % et indéterminée dans 5 % des accidents *(Fig. 4.)*.

Sur cette période, 59 % des accidents de combat sont dûs au facteur humain contre 74 % pour la catégorie école. La proportion d'accidents dûs au facteur humain dans la catégorie combat fluctue de façon importante d'une année à l'autre *(Fig. 5.)*.

Il n'existe pas de différence sensible dans la répartition des causes d'accident entre les périodes antérieure et postérieure à l'introduction des appareils de nouvelle génération. Toutefois, si l'on ne retient que les accidents ayant impliqué des appareils de nouvelle génération *(Fig.6.)*, seulement 53 % des accidents ont été imputés au facteur humain, 6 % à une cause mixte (humaine et technique), 23 % à une cause technique et 18 % à l'environnement (collision aviaire et foudroiement).

Le facteur humain prédomine donc largement en tant que cause principale mais il semble intervenir moins fréquemment sur les aéronefs de combat, en particulier sur les appareils de nouvelle génération.

Il faut noter que le facteur humain intervient également en tant que facteur secondaire souvent aggravant dans les causes dites mixtes. Il serait donc impliqué dans 68 % des accidents de 1977 à 1990 et dans 59 % des accidents sur les aéronefs de nouvelle génération de 1982 à 1990. Il est possible que le facteur humain ait également été responsable d'accidents aériens dont l'imputabilité n'a pu être déterminée.

L'importance du facteur humain dans le risque d'accident aérien a été évalué en fonction du volume de l'activité opérationnelle. Le taux d'accidents imputables au facteur humain, toutes catégories opérationnelles confondues, a fluctué, de 1977 à 1990, autour de 0.25 ± 0.09 accident pour 10 000 heures de vol. Depuis 1987, ces taux d'accidents liés au facteur humain semblent décroître régulièrement *(Fig. 7)*. Les taux d'accidents imputables au facteur humain dans la catégorie combat fluctuent parallèlement aux taux globaux toutes catégories confondues mais restent toutefois nettement supérieurs (0.43 ± 0.15 accident pour 10 000 heures de vol).

2.2. Facteur humain :

En raison de la prépondérance du facteur humain dans les causes d'accident aériens, il était important d'essayer de préciser la nature de ce facteur.

Lorsque le facteur humain a été impliqué, il ne s'agissait jamais d'une cause pathologique. Parmi les causes physiologiques, il n'a pas été retrouvé de pertes de connaissance liées aux accélérations avec les avions de nouvelle génération. Un seul cas, sur Mirage 2000 évoque un facteur de charge de 5.6 $+G_Z$ sans qu'il ait été possible de savoir si le pilote avait perdu connaissance. Le facteur humain le plus souvent évoqué est la désorientation spatiale. Il faut toutefois noter que cette dénomination avancée dans certains dossiers d'enquête semble être utilisée pour caractériser des situations qui dépassent le cadre de mécanismes physiologiques purement sensoriels. En effet, dans ces cas, intervient une mauvaise interprétation de l'évolution de l'appareil.

3. Pertes humaines :

De 1977 à 1990, la proportion d'accidents aériens mortels est de 46 % , dont 30 % en combat et 12 % en école. La comparaison des périodes 1977-1981 et 1982-1990 montre qu'il n'existe pas de différence sensible de la proportion d'accidents mortels depuis l'introduction d'avions de nouvelle génération aussi bien globalement que par catégories. Depuis l'introduction des avions de nouvelle génération, 38 accidents aériens mortels ont été recensés dans l'aviation de combat dont 4 sur les avions de nouvelle génération (2 sur Mirage F1CR et 2 sur Mirage 2000). La proportion d'accidents mortels sur ces aéronefs de nouvelle génération (10.5 % des accidents de combat) est légèrement inférieure au volume de leur activité opérationnelle (13.2 % de l'activité de combat).

Les taux d'accidents mortels ont fluctué, toutes catégories confondues, autour de 0.17 ± 0.07 accident mortel pour 10 000 heures de vol (*Figure 8*). Ces fluctuations sont retrouvées dans la catégorie combat (autour de 0.31 ± 0.15 accident mortel pour 10 000 heures de vol) et dans la catégorie école (autour de 0.14 ± 0.09 accident mortel pour 10 000 heures de vol). Le risque d'accident mortel reste donc plus important dans la catégorie combat malgré une nette tendance à la décroissance depuis 1987.

DISCUSSION

La prédominance des accidents aériens dans l'aviation de combat est cohérente compte-tenu de l'aspect complexe des missions se déroulant dans des conditions environnementales délicates. Depuis la mise en service des avions de nouvelle génération dans l'Armée de l'Air Française, bien que le taux d'accidents dans la catégorie combat ait peu varié, les taux d'accidents des Mirage F1CR et 2000 a été plus important ce qui suggère que le risque d'accidents est plus élevé sur ces appareils que sur ceux de la génération antérieure.

En fait, ce risque est difficile à évaluer pour deux raisons essentielles. D'une part, il n'y a pas eu de transition nette dans l'utilisation de ces deux types d'appareils ce qui biaise toute comparaison globale ou pour la catégorie combat dans son intégralité. D'autre part, les capacités opérationnelles des appareils nouveaux ne sont certainement pas utilisées d'emblée à leur niveau maximal. Par conséquent, l'évaluation du risque d'accidents avec les aéronefs de nouvelle génération au cours des premières années de leur mise en service n'est peut-être pas représentative du risque d'accident à long terme.

Le facteur humain est le plus souvent impliqué dans le déterminisme des accidents. Il est plus fréquemment mis en cause dans les accidents en école pour lesquels il joue un rôle prépondérant dans les processus d'apprentissage. Il joue un rôle important dans les accidents de combat mais paraît être légèrement moins impliqué dans les accidents d'appareils de nouvelle génération malgré un niveau de charge de travail accru sur ce type d'appareil.

Les causes humaines d'accidents n'ont jamais été liées à des processus pathologiques ce qui souligne la qualité de la sélection et du suivi médical des pilotes dans le cadre du contrôle des aptitudes. Des causes purement physiologiques telles que les pertes de connaissance induites par les accélérations $+G_Z$ n'ont pas été mises en évidence dans les accidents aériens bien que le risque existe comme tendrait à le démontrer une enquête anonyme réalisée en 1990 par le Bureau de Sécurité des Vols de l'Etat Major de l'Armée de l'Air. Il faut plutôt s'orienter vers des causes psychophysiologiques dont la principale, avancée dans les enquêtes d'accident, est la désorientation spatiale. Cette cause est fréquente dans les statistiques des forces aériennes étrangères utilisant des avions de nouvelle génération. Les travaux d'ALBERY et Van PATTEN 1990, MONTGOMERY et coll. 1990 et WANSTALL 1990 montrent que la désorientation spatiale est à l'origine d'une proportion importante d'accidents aériens dans l'U.S. Air Force. Dans la majorité des cas, il s'agit d'accidents dits de type I, c'est à dire avec une absence de perception par le pilote de sa désorientation spatiale (TRUMBO et MONTGOMERY 1990). En fait, il semble que le concept de désorientation spatiale au sens strict ne représente qu'une fraction des processus mis en jeu dans ce type d'accident. Dans ce type d'accident, il faut plutôt considérer la désorientation du pilote sur le plan spatio-temporel et sur le plan tactique (MENU et AMALBERTI 1990).

Les pertes humaines consécutives aux accidents aériens dans l'Armée de l'Air Française se sont maintenues à un niveau stable dans l'aviation de combat sans variation notable depuis l'introduction des appareils de nouvelle génération. Ces appareils n'engendrent donc pas une augmentation de la gravité des accidents aériens.

CONCLUSIONS

De 1977 à 1990, malgré la mise en service d'avions de nouvelle génération il ne semble pas exister de variation perceptible de la fréquence des accidents aériens dans l'aviation de combat de l'Armée de l'Air Française bien que les taux d'accidents soient plus élevés avec les avions de nouvelle génération. Le facteur humain reste la cause principale des accidents au cours desquels la désorientation du pilote est le phénomène psychophysiologique le plus fréquent sur ces aéronefs. Les pertes humaines au cours des accidents ayant impliqué les aéronefs de nouvelle génération ont été sensiblement réduites depuis 1987.

Les auteurs remercient le Bureau de sécurité des vols de l'Etat Major de l'Armée de l'Air qui a autorisé La publication des statistiques de l'Armée de l'Air sur les accidents aériens ainsi que le Bureau Sécurité des Vols du Centre d'Etudes et de Recherche de Médecine Aérospatiale pour ses conseils à propos de la rédaction du présent travail.

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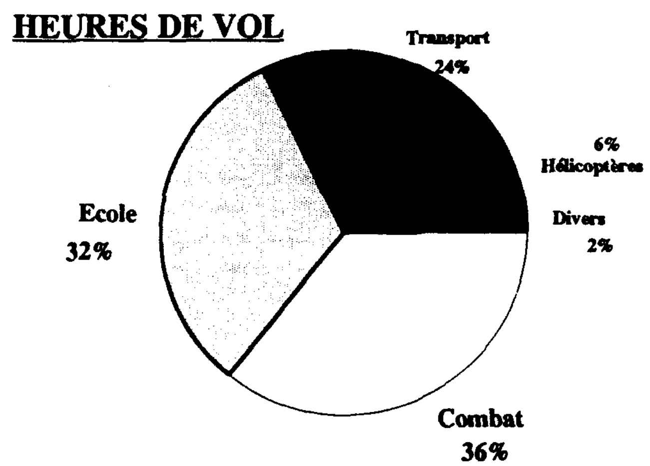
Fig. 1. Proportion de l'activité aérienne et du nombre d'accidents dans l'Armée de l'Air Française de 1977 à 1990.



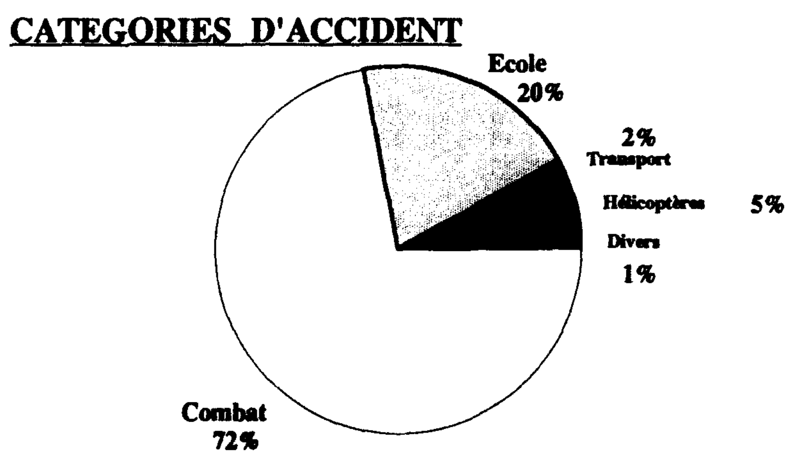


Fig. 2. Distribution du taux d'accidents aériens de 1977 à 1990 dans l'Armée de l'Air Française.

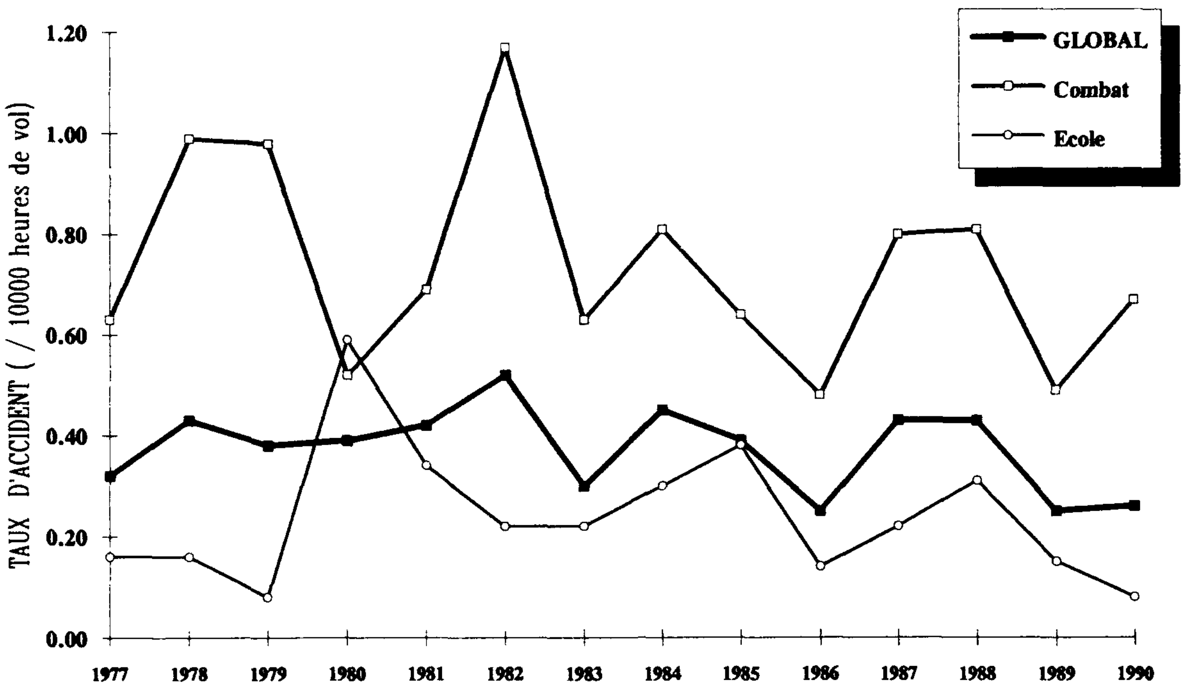


Fig. 3. Evolution du taux d'accident dans la catégorie "combat " et pour chaque aéronef de nouvelle génération de 1982 à 1990.

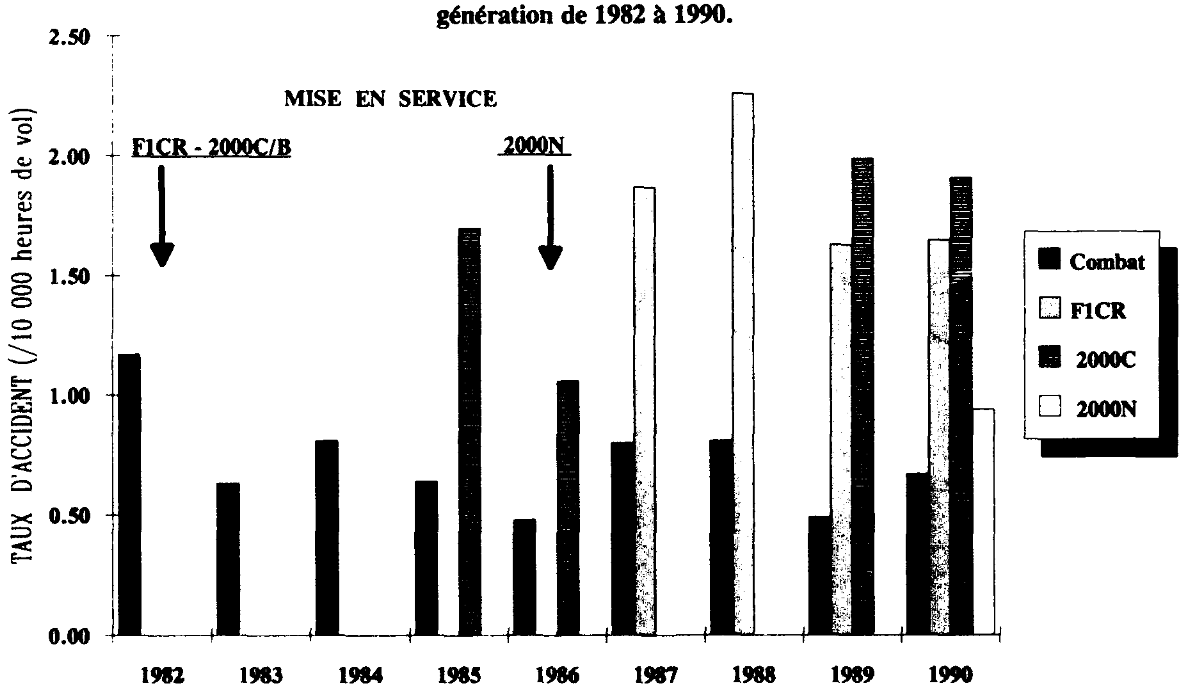


Fig. 4. Imputabilité des accidents aériens dans l'Armée de l'Air Française de 1977 à 1990.

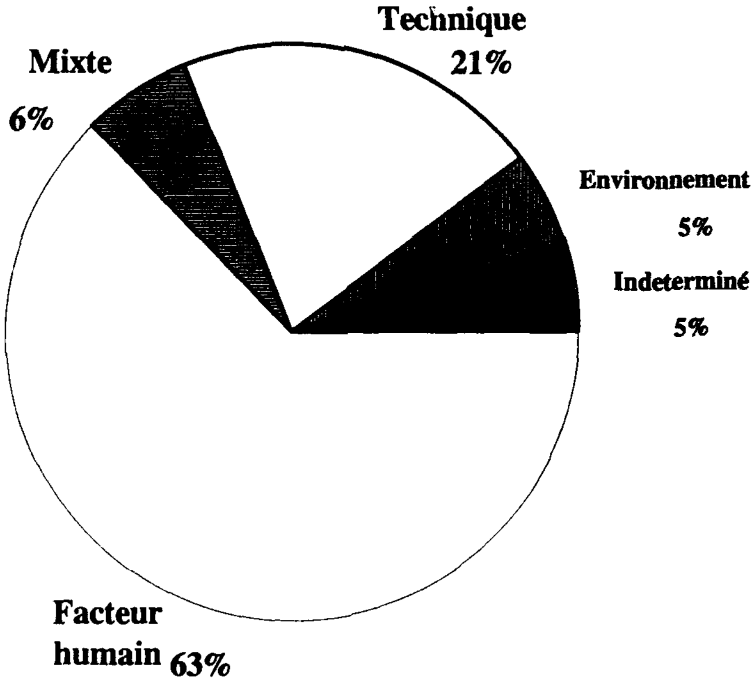


Fig. 5. Evolution de la proportion relative d'accidents dûs au facteur humain pour les catégories "combat" et "école" de 1977 à 1990.

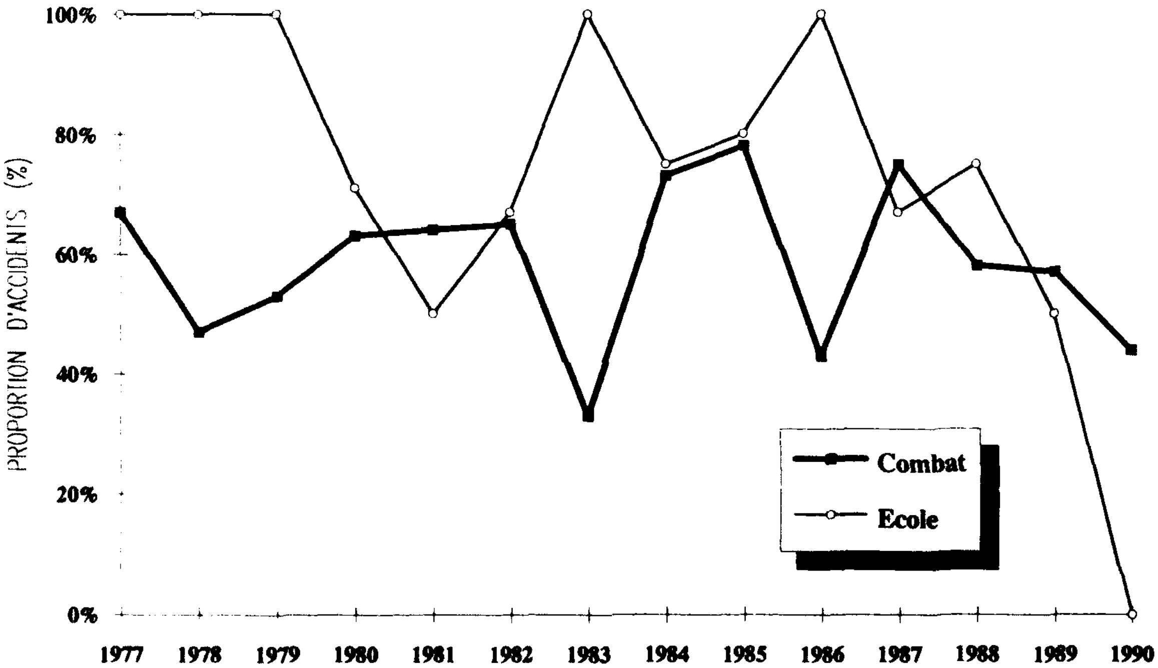


Fig. 6. Proportion d'accidents aériens imputables au facteur humain seul ou associé à d'autres causes dans l'Armée de l'Air Française.

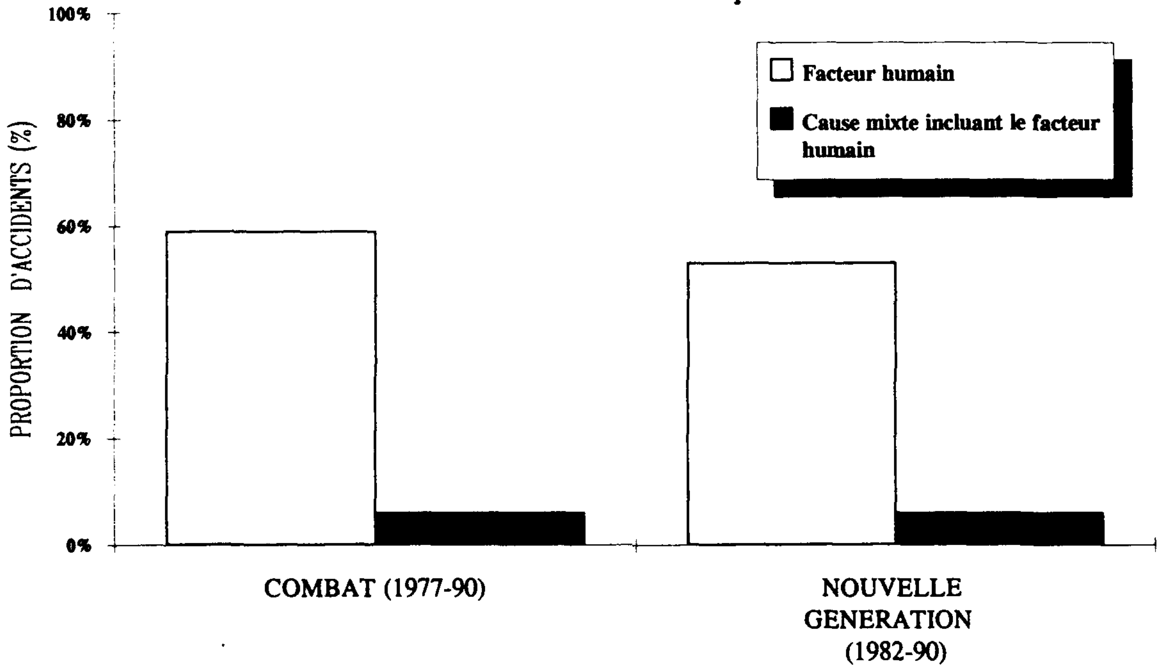


Fig. 7. Evolution du taux d'accidents aériens imputables au facteur humain toutes catégories confondues et dans la catégorie "combat" de 1977 à 1990.

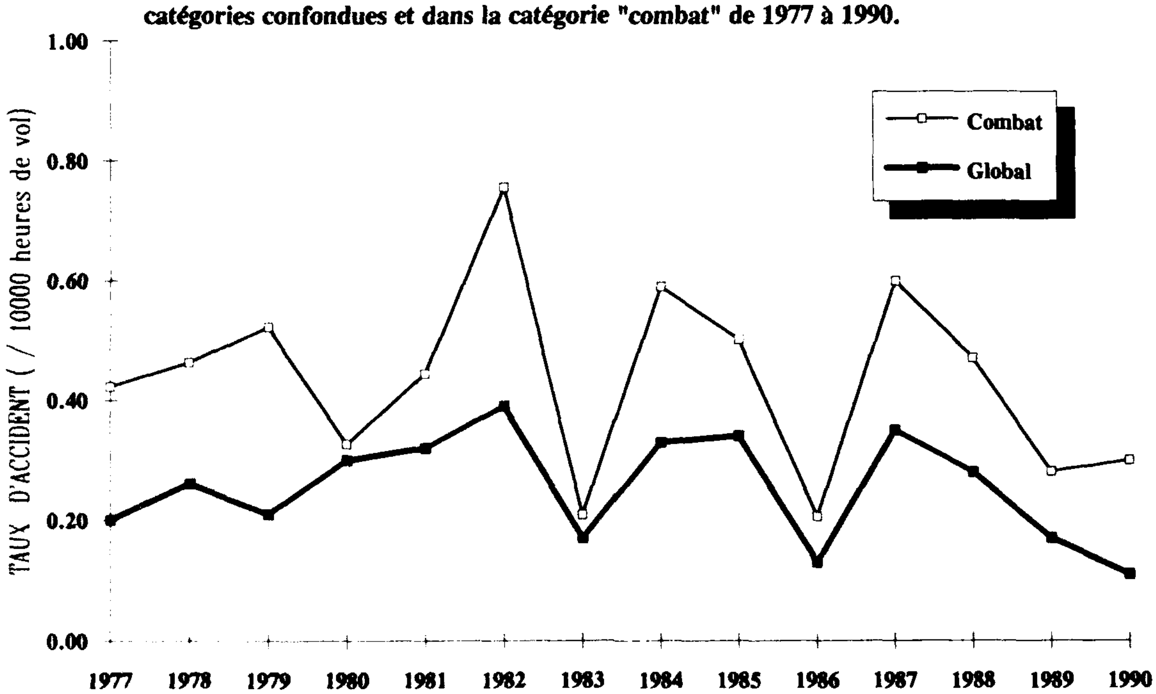
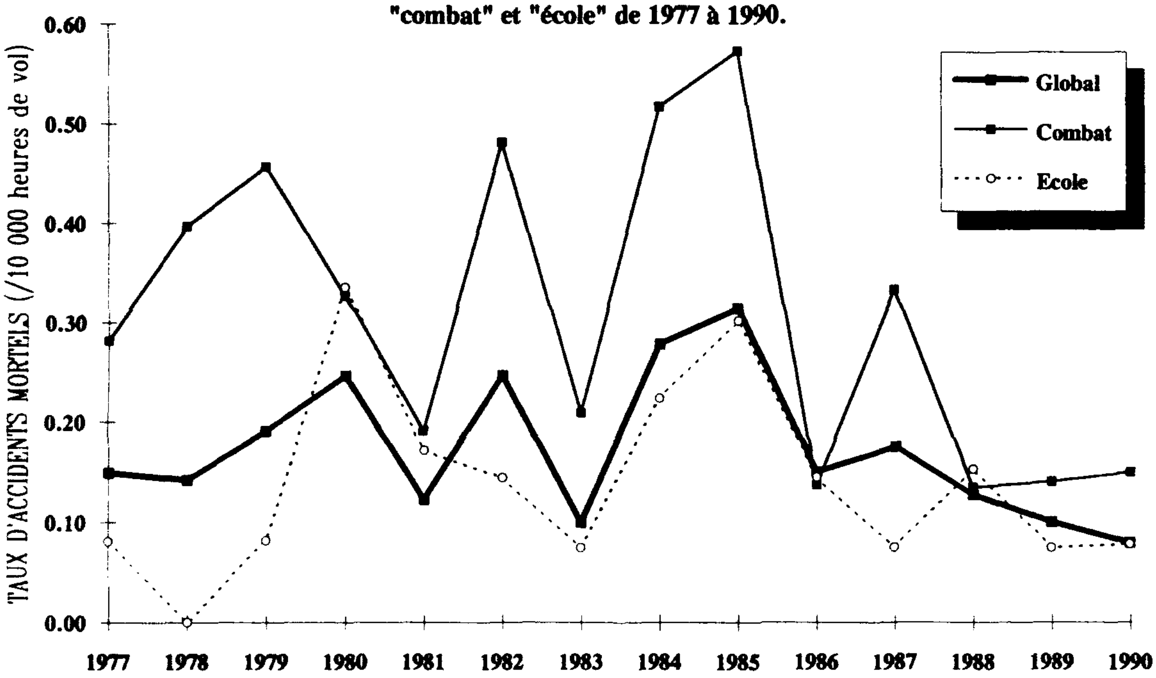


Fig. 8. Evolution du taux d'accidents mortels toutes catégories confondues et pour les catégories "combat" et "école" de 1977 à 1990.



COMBAT AND TRAINING AIRCRAFT CLASS A MISHAPS IN THE BELGIAN AIRFORCE 1970-1990

by

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SUMMARY

The authors reviewed the files of 114 combat and training aircraft class A mishaps in the Belgian Air Force during the period from 1970-1990 with the cooperation of the office of the "Belgian Accident Investigation Board".
They searched for the causes of these accidents i.e. Operational related, Logistics related and environmental factors, as well as contributory factors which played a role in these mishaps.
While considering the causes of these accidents, they found that 71 % were operational related, 22% logistics related and 7% were caused by environmental factors, such as birdstrike, foreign object damage (FOD) to the engine and unknown. From the 23 training aircraft lost, only one single aircraft crash was caused by a technical failure.
The overall attrition rate for the period was 1.08/10.000 Aircraft Hours (A/C) hours, being 1.43/10.000 for combat A/C and 0.55/10.000 for training A/C. The introduction of the agile F-16 fighter in the early 80, coinciding with a serious decrease of the annual flying time and an undermanning in terms of experienced pilots in the squadrons was most probably responsable for the negative trend in the evolution of the annual attrition rate until 1989.
Although the Belgian Air Force remained two years without a major accident, it must resolutely continue its effort in the field of accident prevention. By extending the time spent by aircrews in an operational squadron, supervised by experienced pilots, the Belgian Air Force should be able to reduce class A mishaps in the future.

INTRODUCTION

- In the first 1991 issue of the Belgian Air Force flight safety magazine the Chief of Air Staff congratulated all Air Force personnel for the fact that 1990 had been the first year in Belgian military aviation history without a single class "A" mishap. This was in sharp contrast with the actions which had to be taken a few years earlier. At that time and after a dramatic series of aircraft accidents, the Chief of Air Staff had to order, amongst other measures;
  - special regulations for flights abroad,
  - important changes in the command and control procedures,
  - and a semestrial safety reflection day in all squadrons and at all command levels,
    in order to encourage actions and initiatives to stop entirely or, at least, reduce significantly this very high accident rate.

Since then, on 20 Dec 1991, the Belgian Air Force celebrated its second "class A mishap free" anniversary.
- To maintain the Air Force's professional capability at the highest possible level as an important tool in defensive and offensive air operations, its pilots must be able to train intensively in a realistic environment. Such training implies a permanent accident risk, and it remains a continuous challenge to find the proper balance between flying operationally and flying safely. Bearing this in mind, one of the highest priorities of Chief of Air Staff is to reduce aircraft losses as much as possible, and this for several reasons:
- Firstly, all too often, we have to deplore the loss of lives of highly trained and qualified young men.
- Secondly, the loss and replacement of valuable hardware in a period of spiraling costs and budgetary restrictions is hard to accept both for military and civilian authorities
- Finally, training over a densily populated area and in a crowded airspace like Western-Europe, inevitably implies the risk of loss of civilian lives and substantial damage to civilian property. This in turn - especially in a period of general détente - may lead to flying restrictions being imposed by the highest civilian authorities, thus seriously limiting future training possibilities.

THE ACCIDENT INVESTIGATION BOARD (AIB)

- Flight safety begins with a thorough investigation of each aircraft accident to find the cause of the mishap. To carry out this task, the Belgian Air Force has created a permanent aircraft Accident Investigation Board (AIB) which is composed of different specialists in the field of aviation. It consists of pilots, technicians (engine, instruments, electronics, safety equipment etc) and a flight surgeon. This team reports directly to the Chief of Air Staff and can, during the investigation, call on the expertise of highly specialized military or industrial laboratories. During the whole investigation the Chief of Air Staff is continuously kept informed, which makes it possible to order intermediate preventive actions. In its final report, the AIB tries to identify the primary cause of the mishaps and considers all factors which contributed to the accident. In addition, and in order to prevent further similar mishaps, the AIB makes a number of recommendations to the Chief of Air Staff.
- Over the last years, the causes of aircraft accidents have been generally divided into the following categories: Logistics-related, Operational-related and Environmental-related. This categorization is adequate, as it not only allows us to present detailed diagrams, but it also offers the possibility to compare the statistics of different Air Forces and different aircraft types. Nevertheless, it is generally accepted that an aircraft mishap is very seldom the result of one single deficiency. It is usually a combination of many factors: technical, human, environmental; as well as other contributory factors.

If the result of the investigation confirms that a technical failure was the cause of the accident, it is obvious that the appropriate step to prevent further similar problems is a corrective technical action which for example could be the introduction of a modification. As an illustration, in the early years of the F-16 we lost an aircraft in unexplainable circumstances. The accident happened during a low-level interception mission. The mishap aircraft impacted with the ground in a 50° bank and nose down attitude without any attempt to eject from the pilot. The accident investigation team found sufficient evidence in the wreckage to prove that the crash was caused by a sudden asymmetry of the leading edge flaps, destabilizing the aircraft in such a severe way, that the pilot did not have sufficient time to regain control. As a result of the investigation report, an asymmetry brake system device was retrofitted on all F-16 aircraft, thus considerably reducing the risk of similar accidents. Regrettably, due to engineering and delivery problems, six years later not all F-16 A/B models had been modified. At that time an F-16 instructor pilot was confronted with an asymmetric LEF problem during night flight. A controllability check showed that, although heavy stick forces were needed, the crippled aircraft could be kept under control at a speed above 180 kts. The experienced F-16 pilot, aware of a successful recovery of a USAF F-16 in a similar emergency situation, decided, with the help of an equally experienced wingman, and following the instructions of the Flight Manual, to land at his home base. Shortly before the touch down point, when the speed decreased below 180 kts with the AOA increasing above 10°, the aircraft departed in an uncontrollable rolling nose high manoeuvre. The pilot ejected, unfortunately outside the envelope of the ACES II ejection seat. Although the primary cause of this accident was obviously technical, the human factor undoubtedly played an important role in the fatal outcome of this mishap. Indeed, being an experienced instructor pilot, the pilot's personal pride led him to attempt a landing with his disabled aircraft. Unfortunately, he highly underestimated the difficulty of such a manoeuvre, especially during night flying. After this accident, several pilots retried this emergency on a flight simulator which had been programmed accordingly. All of them experienced enormous difficulties in trying to land the aircraft in similar circumstances.
In its comment on this mishap, the Accident Investigation Board advised: " We have serious doubts about the feasibility and the chances for succes of the procedure mentioned in the Dash One. The smallest error can be catastrophic and the pilot's chances for survival are very low. Also the final outcome is heavily dependant upon various factors. i.e. experience on F-16, day or night, crosswind, turbulence etc".

The above example illustrates the efficiency of the AIB in different fields;
- after the first accident a technical modification was recommended, modification which unfortunately had not been applied at the time the second accident occured,
- after the second accident, in addition to the previously recommended technical modification, a change in the procedures was suggested.
Besides the above examples, a further indication of the efficiency of the AIB is the fact that it is very seldom that the cause of the accident cannot be found. A point which will be illustrated in detail in the following paragraphs.

METHODS.
- At the office of AIB of the Belgian Air Force, we examined 114 class A mishap files of combat and training aircraft, covering the period from 1970-1990. Transport aircraft and rotary wings aircraft were excluded from this study.
- During this timeframe covering the study, the following aircraft were in the inventory of the Belgian Air Force.

1. TRAINING AIRCRAFT.
- SV-4 : A Belgian made piston engine biplane for initial training till 1970
- SIAI MARCHETTI SF-260: An Italian built piston engine aircraft, used for initial training from 1970 to the present.
- FOUGA MAGISTER CM 170: A French twin engine jet for advanced training, used for this purpose from 1960 till 1979. At this moment the aircraft is still in service for continuity training of pilots with a desk job.
- T 33: The US built T- bird, a single engine jet, was used for operational training till 1977.
- ALFA-JET: A franco-german twin engine advanced jet which replaced the Fouga Magister and the T 33 for advanced and operational training.

2. COMBAT AIRCRAFT.
- F/RF - 84: The "Thunderstreak" and "Thunderflash", both US build single engine fighter bomber and tactical Recce aircraft, both out of service in 1971.
- F-104 G : The US build single engine "Starfigther", used as interceptor and as fighter bomber attack/strike from 1963 till 1983.
- MIRAGE 5 B :A French Dassault single engine aircraft used in the fighter bomber attack and recce role from 1970 till the present.
- F-16 A/B: The "Fighting Falcon" of General Dynamic came into the inventory of the Belgian Air Force in 1979 initially in the fighter/ interceptor role and later on, in the fighter bomber attack/strike role.

- We searched for the causes of these accidents i.e. Operational related, Logistic related, Environmental factors and unknown causes. We also investigated on contributory factors which played an important role in the cause of these mishaps e.g. supervision, leadership, violations of regulations, lack of continuity training, psychological factors, physiological stress and pathophysiological condition of the pilot. We checked also the flying status of the mishap pilot i.e. squadron pilot, intructor pilot, visitor pilot or trainee. We studied the numerous ejections which occured during these mishaps and registered the succes rate e.g. pilot uninjured, slightly, severely or fatally injured.

RESULTS:
- 114 aircraft were destroyed during this period; 91 of them were combat aircraft, 23 training aircraft. Also 2 civilian an 1 French bomber were lost in midair collisions involving our planes, adding 5 fatalities. In a number of cases, the ground impact caused extensive damage to civilian properties and 20 civilians lost their lives during these accidents.
- A total of 134 pilots and 1 passenger were involved in these crashes and 62 (46%) of them were killed. Two other pilots were declared permanently unfit even for a limited flying, after suffering major physical injuries .
- 64 pilots were able to eject from their disabled aircraft. Due to ejections out of the seat envelope (8) or malfunctioning in the ejection sequence system (2) 10 of them were fatally injured, 25 were

unhurt; 29 sustained light (8) or severe (21) injuries. The injuries suffered by these pilots were substantially light to moderate compression fractures of the lower thoracic and upper lumbal vertebrae (15) and to a lesser degree, fractures ofthe lower (4) and upper extremities (1) and burns (1). After recovery from their injuries, which took an average time of 4 to 5 months, 15 of the 21 injured pilots were able to regain their previous flying status, while 6 of them were subject to medical restrictions (i.e. temporarily or permanently unfit for aircraft with ejection seat)

- While considering the causes of these 114 class A mishaps, we found that 81 (71%) were operational related, 25 (22 %) logistics related, 6 (5,3%) were caused by environmental factors such as a bird strike or an unidentified foreign object damage (FOD) to the engine, and the remaining 2 were classified as unknown . It should be emphasized that our conclusion do not always reflect the unanimous opinion of the AID. Indeed, when the investigation reveals that a technical problem cannot be totally ruled out, the Commission must report an " Unknown cause" For 5 mishaps, there was a strong indication toward spatial disorientation. Although failure of the main attitude indicator could not been excluded, these mishaps have been categorized as operational-related rather than unknown. The overall attrition rate per 10.000 Aircraft flying hours could be computed as being 1.08 per 10.000 aircraft hours.

- Because, there is a great difference in operations between Combat aircraft and Training aircraft, we had to expect a great difference in causal factors and attrition rates between these aircraft categories. Therefore, we have divided this chapter in 2 parts: Combat aircraft and Training aircraft.

1. COMBAT AIRCRAFTS:

From 1970 till 1990, we lost 91 combat aircraft; 41 Mirage 5 B, 23 F-104G, 24 F-16 A/B and 3 F 84-F. These aircraft accumulated 636,000 flying hours, resulting in an overall attrition rate of 1.43 / 10,000 flying hours.

- 59 (65 %) mishaps were operational-related .

Midair collisions:	15
Spatial disorientation (SDO):	12
Collision with the ground/obstacle(CWG) :	11
Loss of control (LOC):	9
Take off / Landing:	6
Approach in IMC:	2
Fuel management:	2
Ricochet :	1
Engine management (stall):	1

- 25 (27,5 %) A/C mishaps showed to have a logistic factor as primary cause.

Engine :	16
Landing gear :	3
Flight controls :	3
Fuel system :	2
Electrical :	1

- 5 other aircraft crashed after a bird strike or FOD ingestion to the engine.

Looking at the 2 remaining mishaps; one was categorized as unknown, while the second one was caused by an unauthorized flight of a technician!

- Contributory factors frequently intervened in the cause of these accidents and very often more than one factor contributed to the mishap. We discovered, in order of importance, the following contributory factors:

	MIR 5	F104	F16	F84	TOT
Impr.emerg. techniques	12	4	2	-	18
Inexperience	8	3	4	2	17
Violations of regulations	6	2	8	-	16
Supervision	4	2	3	-	9
Psychological	5	2	2	-	9
Leadership	7	-	2	-	9
Continuity training	-	2	1	-	3
ATC procedures	1	-	1	-	3
Pathophysiol.	2	-	1	-	3
Physiological accelerations	-	-	2	-	2

2. TRAINING AIRCRAFT:

- Investigating the causes of these mishaps, we discovered that from the 23 planes lost, not one single aircraft crashed due to technical problems, 22 were operational-related and one was lost after a bird strike.

OPERATIONAL RELATED

	LOC	CWG	TO/LAND	FUEL	MID AIR	ATC PROC.
10 CM 170	6	1	3	-	-	-
7 SF 260	2	2	1	2	-	-
3 T-33	1	1	-	-	1	-
2 ALPHA JET	1	-	-	-	-	1
22 Training aircraft	10	4	4	2	1	1

PILOT CATEGORY

	STUDENT	I.P.	VISITOR
10 CM 170	3	1	6
7 SF 260	1	5	1
3 T-33	1	1	1
2 ALPHA-JET	1	1	-
22 Training A/C	6	8	8

As contributory factors to these training aircraft accidents we noticed

	CM 170	ALPHA JET	T 33	SF 260	TOT
Inexperience	8	1	2	3	14
Violations of regulations	6	1	1	1	9
Continuity training	5	1	1	-	7
Supervision	4	1	-	1	6
Psychological	4	-	1	-	5
Improper emerg techn.	1	-	-	1	2
Intoxication	1	-	-	-	1
ATC procedures	-	1	-	-	1

ANALYSIS

1. COMBAT AIRCRAFT.

- Analyzing the evolution of the attrition rate of combat aircraft we notice a negative trend over the last 12 years, until 1989. Starting with an average of 1.27/10.000 Hrs over the first 9 years covering 320,000 flying hours, the attrition rate increased to 1.60/10,000 Hrs for the last 12 years covering 310,000 hours. The turning point of this graphic is situated in the period 1979-1982, coinciding with a dramatic decrease of the annual flying time per pilot from 200 Hrs to an historical low of 120, and later climbing again to the present-day 170 hours per year. At the same time we saw the introduction of the new highly maneuverable F-16 Fighting Falcon and it was the Belgian Air Force which assigned the first operational West European F-16 air defence squadron to NATO.

- Air combat manoeuvering with an F-16 was for the fighter pilots a great joy, but the tactics with the agile fighter had to be totally reviewed. Thanks to a turn radius which was 3 times tighter than before, the former F-104 pilot saw his combat airspace reduced 27 fold. It took him some time to realise that, due to the important improvement in manoeuverability, it was no longer a simple matter of remembering a mentally plotted position of the "enemy" in space after an evasive manoeuvre. The dynamic situation of the air combat environment changed so quickly, that the pilot had to anticipate the "enemy" to show up at unexpected places, which forced him to the highest degree of mental alertness. Two midair collisions resulting in 4 aircraft losses, were the price we had to pay to learn this lesson.

- Another element which could have played an important role in this high attrition rate ,is the fact that due to the call of civilian airlines for military pilots the squadrons became significantly undermanned in terms of experienced pilots during this period. In a flying squadron this has two important consequences. Firstly a greater part of the working day must be spent on non flying duties. Secondly the most complex missions must be executed by a small number of experienced pilots, thereby reducing their availability to monitor the progress of junior squadron pilots.Consequently the junior pilot's progression in operational flying will be disturbed, which in turn can lead to a decreasing motivation and become hazardous for flight safety.

- We also would like to comment on the important number of accidents due to spatial disorientation (SDO). SDO is characterised by the high fatality rate. Indeed , if the pilot is unaware of the real attitude of his aircraft and if he does not know what is going on, he can impossibly take any corrective action. Whith regard to the SDO problem, we welcome the articles in a Dutch Flight Safety magazine, where we could find the personal impressions of the pilots who had experienced SDO during their missions

- Comparing the 3 main aircraft, operating during these 21 years, we notice that the F-104 had the lowest attrition rate (1.18) during the period 70 - 83, although its overall rate was 1.33 for its total life time in the Belgian Air Force (1963-1983). This was lower than the Mirage (1.55) and the F-16 (1.65). The nickname "Widowmaker" which this aircraft earned during its service in the West-European Air Forces was most probably due to its higher fatality rate (0.8/10.000 hours) due to less ejections and due to the high accident rate in the German Air Force in the initial stage. On the other hand, we should emphazise that we only lost 4 of the 23 aircraft for technical reasons, while this factor was responsible for more then 30% of the Mirage and F-16 mishaps.

It has to be noted however that in the beginning only experienced pilots (1.500 hrs total flying time) went to the F104 Squadrons. With the introduction of Mirage 5 and F-16, and due to the lack of a "maturation" aircraft, pilots flew those performant combat aircraft after a total of less than 400 hrs on training aircraft

- For the Mirage 5, improper emergency technique as a contributory factor was very often mentioned. This could have been due to the non availability of a flight simulator in Belgium. Young Mirage pilot train their conversion course on a flight simulator in France. When flying at low level, if experiencing a serious engine problem, the pilot is not allowed to make the smallest mistake. Indeed, he has to be able to analyse the engine problem in very short timeframe, followed by an appropiate action, considering ejection, often over a densily populated area, with a 0-90 ballistic ejection seat. This seat has been recently replaced by a 0-0 rocket seat.

- Finally, we noticed that we didn't have any documented case of an F-16 mishap due to +Gz induced loss of consciousness, although in 2 mishaps, +Gz forces could have contributed to the loss of an aircraft.

2. TRAINING AIRCRAFTS.

- We were amazed to notice the high fatality rate in training aircraft mishaps. Indeed, 21 of the 35 pilots involved were killed during these crashes . At the first sight, we believed that this was due to the fact that the majority of these planes were not equiped with an ejection seat. However further analysis of these accidents confirmed that very few pilots could have been saved as such, because almost all fatal accidents occured after loss of control at low level, out of envelope of any ejection seat.

- It is also quite remarkable that only 12 of the 23 aircraft were destroyed in relation with the training program. The other were lost by IP (3) or by visitor pilots (8). Although only an estimated 20 % of the total aircraft flying hours are consumed by these 2 categories of pilots, they were involved in almost 50% of all Training aircraft mishaps. The visitor pilot is a pilot with a temporarily deskjob and the Air Staff gives him the opportunity to maintain flying currency with a limited flying program. These pilots fly between 40 and 60 flying hours a year, of wich a certain amount in the back seat.

- During 5 years, the Fouga Magister were dispersed at 5 different airfields with insufficient supervision of the flying activities of these visitor pilots. This situation resulted in a series of fatal crashes. The AIB mentioned in almost all cases the following contributory factors in these mishaps: lack of supervision, lack of continuity training, and thus poor preparation, violation of regulations and non familiarity with typical aircraft flight characteristics.

- In order to stop these disasters, the Air Staff took the wise decision to withdraw the Fouga Magister from the 5 air bases and to centralize them in a newly created squadron for visitor pilots, supervised by a small, but permanent staff of highly experienced IP on this type. By taking this measure, the Air Staff could influence the Human Factor in such a way that during more than 4 years not one single mishap has happened to a Fouga Magister .

- In another study of about 100 class A and B mishaps in the Belgian Air Force, we found a positive correlation between even a short break in training continuity and the occurence of an accident. It could be demonstrated that 20% of all mishaps took place after a flying interruption of one week, although these flights represent only 5 % of the total of the missions flown.

CONCLUSION

- Although the Belgian Air Force remained two years without an accident, it must resolutely continue its efforts in the field of accident prevention. Flight safety must be a continuous concern of all personnel serving in the Air Force. The airman who picks up a foreign object on the taxi-track, the crew chief with a carefully performed pre and post flight inspection, the highly skilled maintenance personnel, which is responsible for repair and control of complicated hardware and software, the air traffic controller who must guide and talk-down his aircraft with great precision in difficult weather conditions, the alertness of the fire brigade and the flight surgeon, who by his knowledge of aerospace medicine and his interest in flying activities has become a trusted ally of his pilots, all have their part to play.

A lower defence budget together with a new NATO strategy which aims to lower the readiness state of our operational squadrons, are both forcing the Belgian Air Staff to substitute fully combat ready squadron pilots by an important number of Operational Reserve pilots (OR). These OR pilots are ex-squadron pilots with a temporarily Staff function. Each week they have a dedicated flying day in their assigned squadron, so that they can continue to fly about 60 to 80 hours a year on combat aircraft, and this for a maximum of three to five years. Specific measures have been taken by the Air Staff to give these pilots an adapted training program, and to avoid flight safety hazards. The Air Staff is well aware of the dangers linked to the OR status. An intensive flight safety policy should however reduce the risks of those "economically induced" hazards.

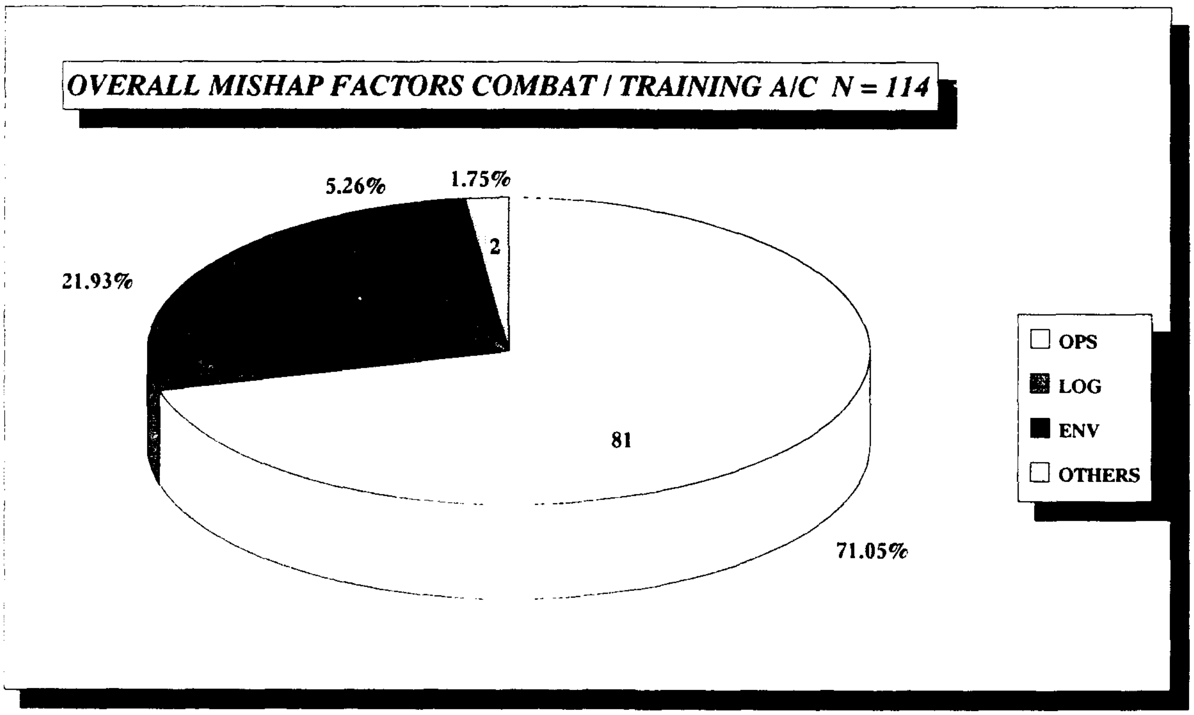
- The squadron pilot must be able to fully concentrate on his flying activities, and to reduce as much as possible the work load and the troubles very often created by staff work and by attending external courses. He should further fly in a well manned squadron where the young pilot is surrounded by experienced pilots, with whom he can train and discuss his problems. At least, we should plead to keep the pilots in the squadrons for a longer time. We often notice that young pilots are already leaving the squadrons after 4-5 years which represents, at the rate of the annual flying time of 170 hours a year, only 750 to 800 hours of experience on combat aircraft. These pilots have to be very good to assume the function as CO of a squadron after an assignment of 3 years in the Air Staff, with the consequent reduction in experience at the front line.

- Over the last 21 years, the Belgian Air Force lost 114 Aircraft and 62 pilots during peace time operations. We payed a very high price, to provide NATO with an operational Air Force . The statement: "The pilot is the only soldier of the Armed Forces, who permanently risks his life in peace time" is a hard reality.

ATTRITION / FATALITY RATE

COMBAT A/C	A/C TYPE	N MISHAP A/C	FLYING HOURS	ATTRITION RATE	FAT	FAT RATE
	F-16 A/B	24	145179	1,65	11	0,76
	MIR 5 B	41	263836	1,55	16	0,60
	F 104-G	23	194696	1,18	13	0,66
	F-84 F	3	30908	0,97	1	0,32
	TOTAL	91	634619	1,43	41	0,64
TRAINING A/C	A/C TYPE	N MISHAP A/C	FLYING HOURS	ATTRITION RATE	FAT	FAT RATE
	CM-170	11	120718	0,91	8	0,66
	SF-260/SV-4	7	189937	0,37	7	0,37
	ALPHA-JET	2	67335	0,30	3	0,44
	T-33	3	41012	0,73	3	0,73
	TOTAL	23	419002	0,55	21	0,50
OVERALL		114	1053621	1,08	62	0,59

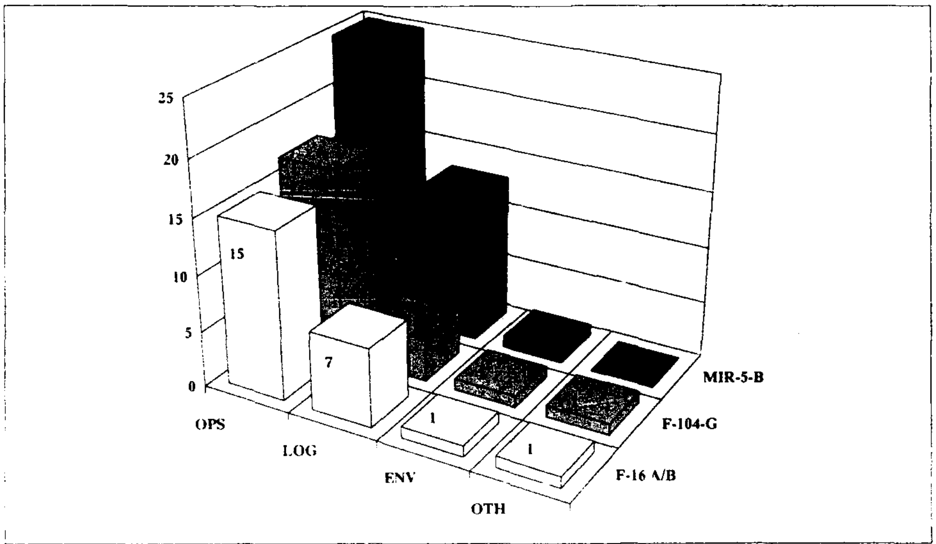
A1



A2

MISHAP COMBAT AIRCRAFT

MIR 5 B N = 41	F-16 A/B N = 24	F-104-G N = 23
ATTRITION : 1,53/10.000	ATTRITION : 1,65/10.000	ATTRITION: 1,12/10.000
FATALITIES : 0,6/10.000	FATALITIES: 0,6/10.000	FATALITIES: 0,8/10.000
EJECTIONS : 30/47	EJECTIONS: 18/26	EJECTIONS: 12/24



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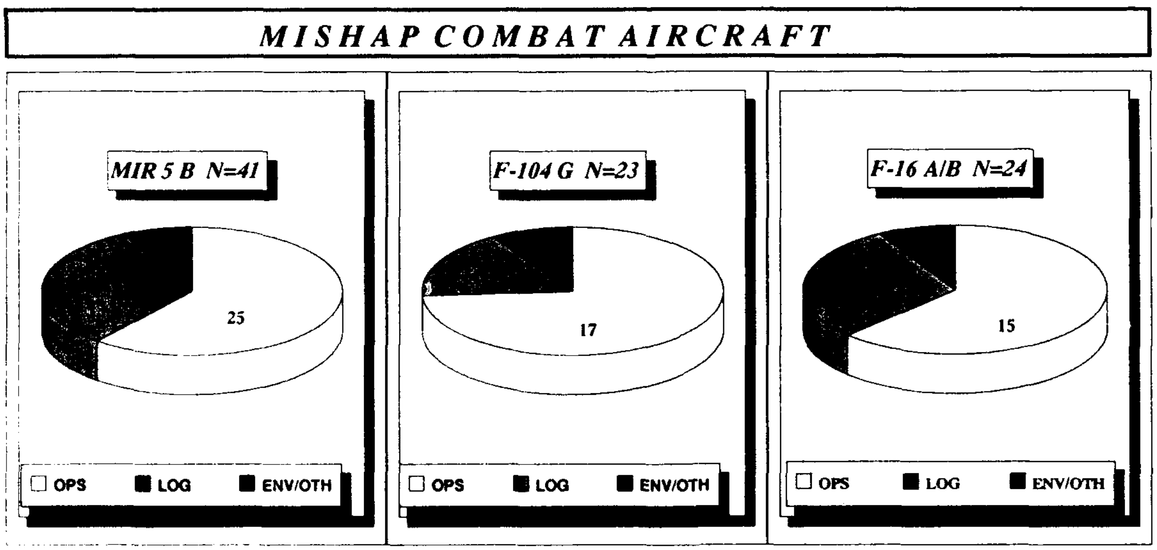

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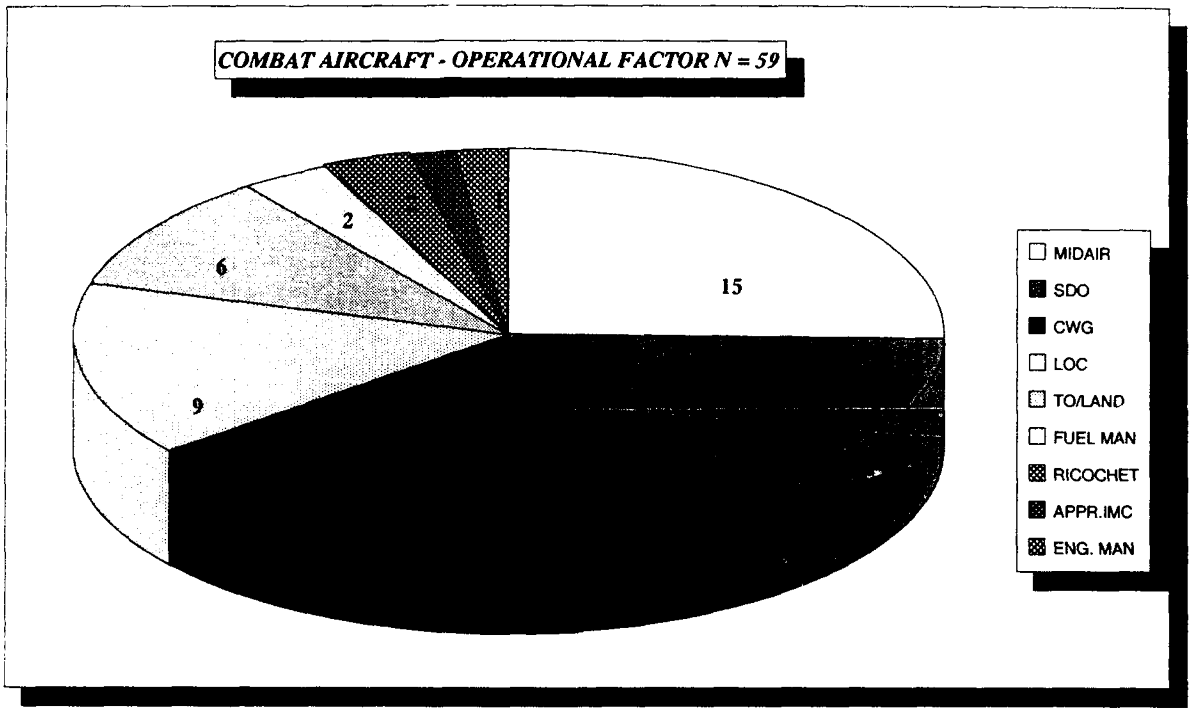
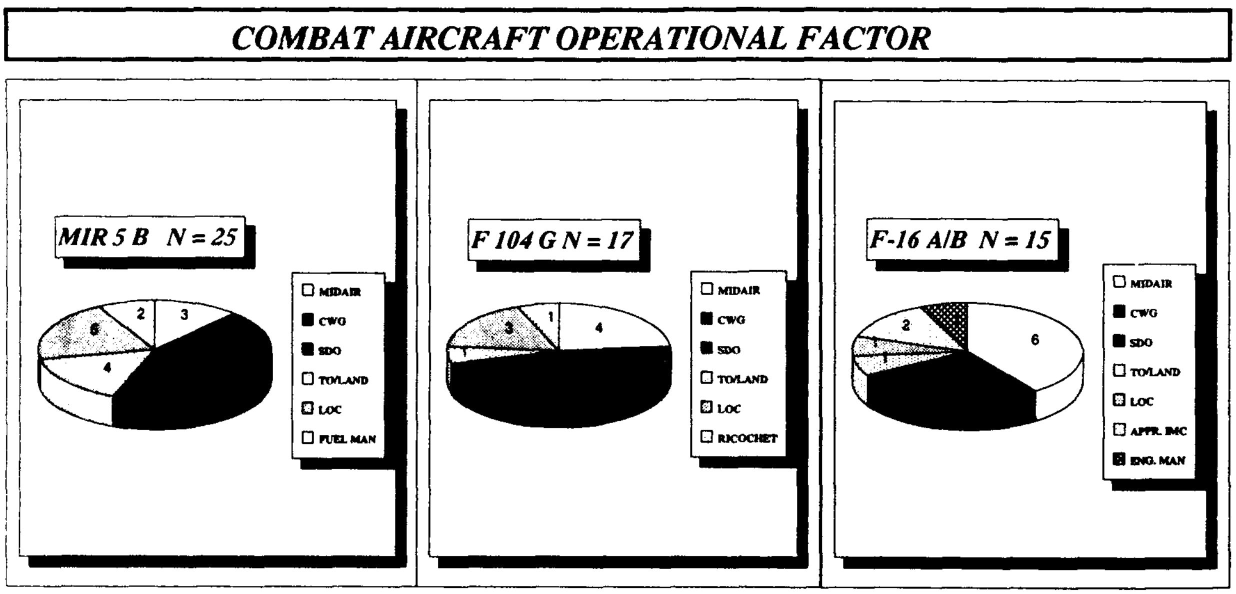


COMBAT AIRCRAFT - OPERATIONAL FACTOR N = 59
15
9
6
2
MIDAIR
SDO
CWG
LOC
TO/LAND
FUEL MAN
RICOCHET
APPR.IMC
ENG. MAN

A5



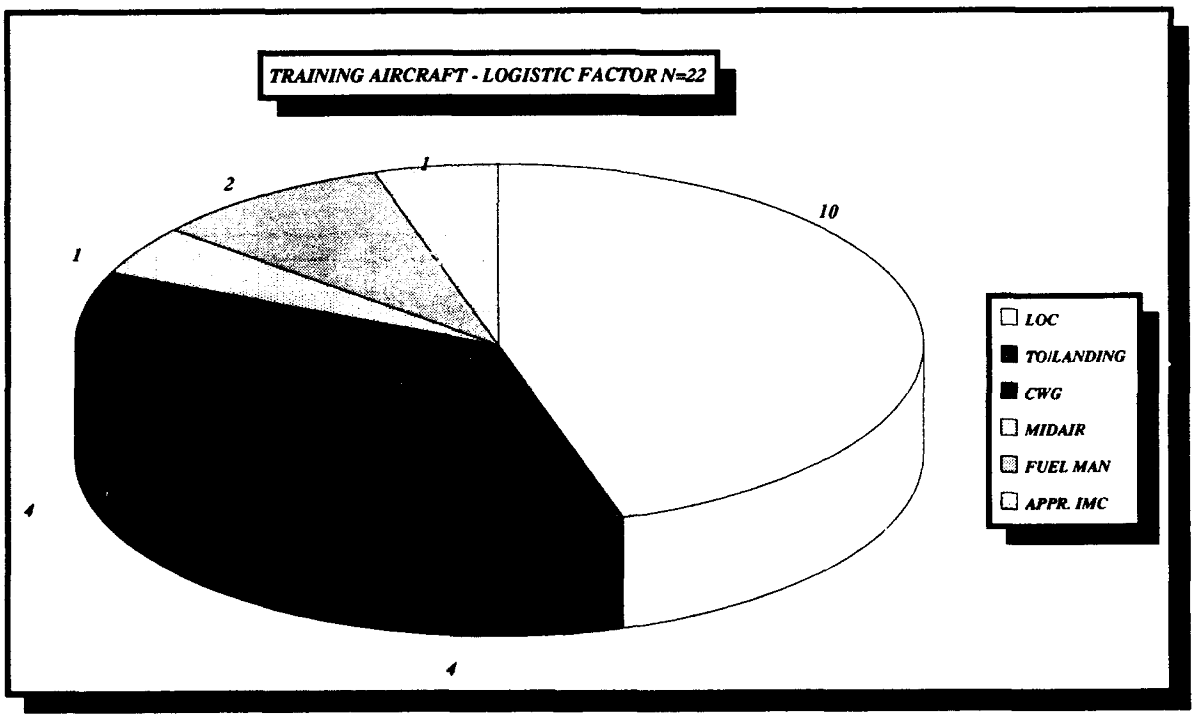
COMBAT AIRCRAFT OPERATIONAL FACTOR
MIR 5 B N = 25
2
3
6
4
MIDAIR
CWG
SDO
TO/LAND
LOC
FUEL MAN
F 104 G N = 17
1
4
3
1
MIDAIR
CWG
SDO
TO/LAND
LOC
RICOCHET
F-16 A/B N = 15
2
6
1
1
MIDAIR
CWG
SDO
TO/LAND
LOC
APPR. IMC
ENG. MAN

A6

TRAINING AIRCRAFT

A/C TYPE	NUM	OPS	LOG	ENV	OTH
CM-170	11	10	-	1	-
ALPHA-JET	2	2	-	-	-
T-33	3	3	-	-	-
SF-260/SV-4	7	7	-	-	-
TRAINING A/C	23	22	-	1	-

A7



A8

FLYING STATUS PILOT / TRAINING A/C MISHAP

A/C TYPE	NUMBER	STUDENT	I/P	VISITOR
CM-170	11	3	2	6
ALPHA-JET	2	1	1	-
T-33	3	1	1	1
SF-260/SV-4	7	1	5	1
TRAINING A/C	23	6	9	8

TRAINING RELATED 12

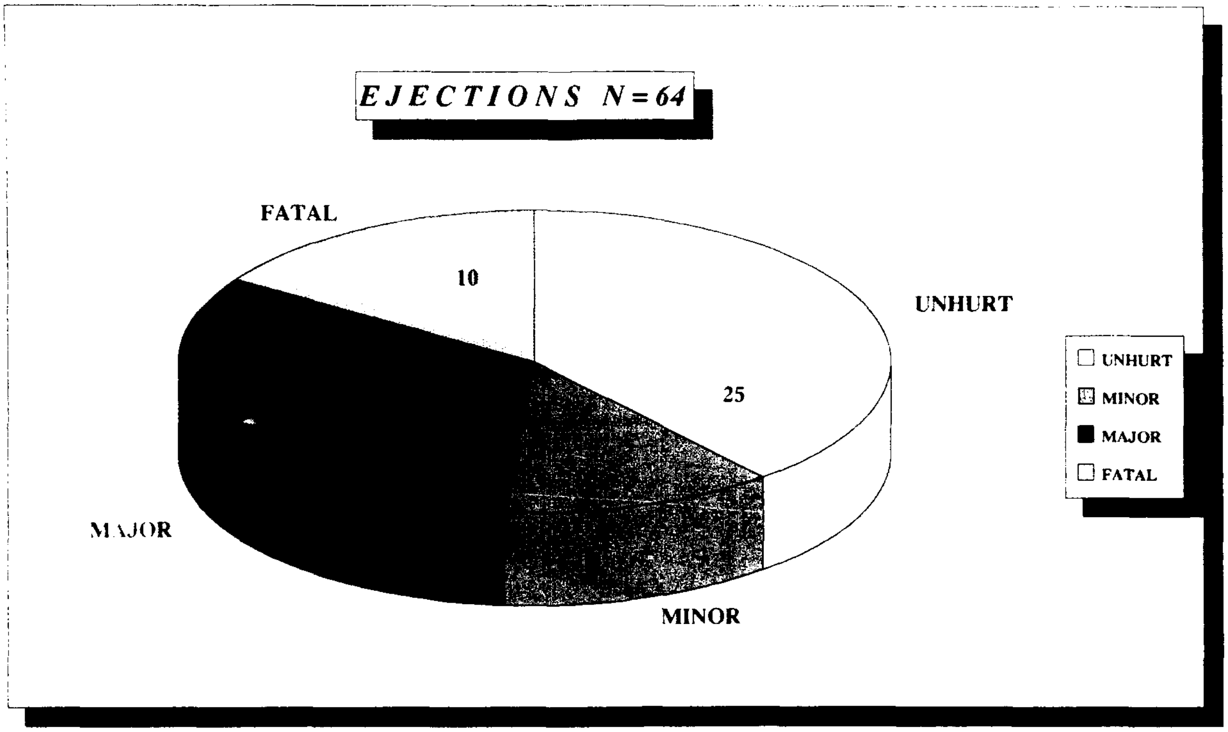
NOT TRAINING RELATED 11

A9

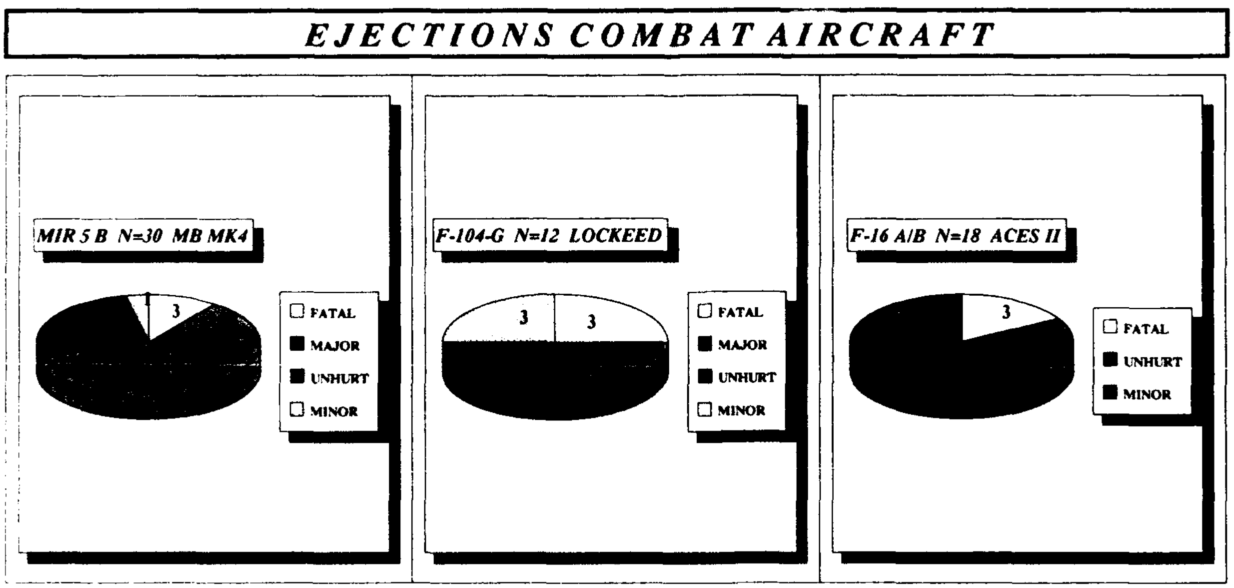
EJECTIONS

A/C TYPE	SEAT	N-A/C	N-PIL	N-EJEC PIL	FATAL	MAJOR	MINOR	UNHURT	FIT	UNFIT	RESTRICT.
MIR 5B	MB MK 4	41	47	30	3	18	1	8	21	-	6
F 104 G	LOCKEED	23	24	12	3	3	3	3	9	-	-
F-16 A/B	ACES II	24	26	18	3	-	2	13	15	-	-
F-84 F	REPUBLIC	3	3	2	-	-	1	1	2	-	-
T-33	LOCKEED	3	4	2	1	-	1	-	1	-	-
ALPHA-JET	MB MK 10	2	3	0	-	-	-	-	-	-	-
		96	107	64	10	21	8	25	48	-	6

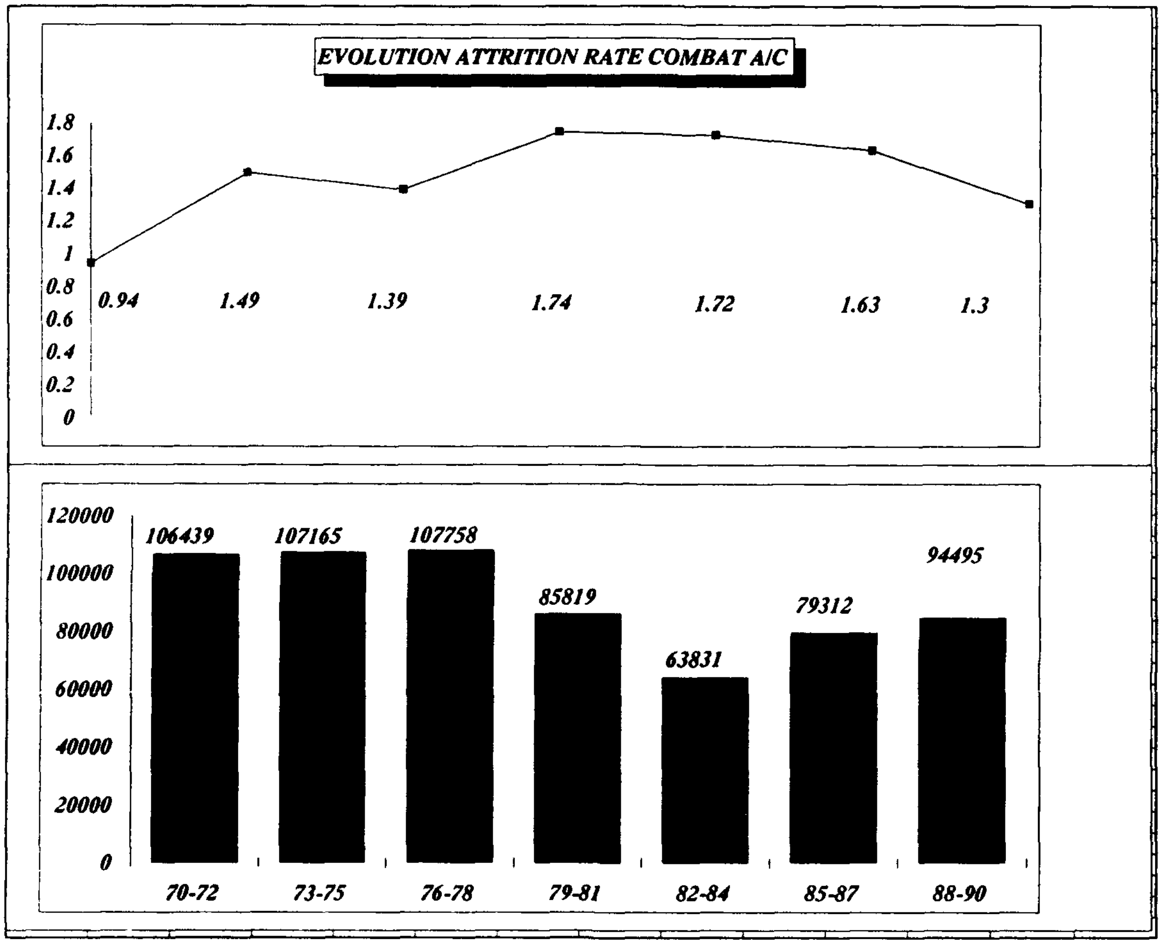
A10


EJECTIONS N=64
FATAL
10
UNHURT
25
MAJOR
MINOR
UNHURT
MINOR
MAJOR
FATAL

A11


EJECTIONS COMBAT AIRCRAFT
MIR 5 B N=30 MB MK4
3
FATAL
MAJOR
UNHURT
MINOR
F-104-G N=12 LOCKEED
3
3
FATAL
MAJOR
UNHURT
MINOR
F-16 A/B N=18 ACES II
3
FATAL
UNHURT
MINOR

A12


EVOLUTION ATTRITION RATE COMBAT A/C
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.94
1.49
1.39
1.74
1.72
1.63
1.3
120000
100000
80000
60000
40000
20000
0
106439
107165
107758
85819
63831
79312
94495
70-72
73-75
76-78
79-81
82-84
85-87
88-90

UNDERLYING CAUSES OF HUMAN ERROR IN U.S. ARMY ROTARY WING ACCIDENTS

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SUMMARY

Human error has been a causal factor in 80% of U.S. Army aviation accidents. The focus of an accident investigation is to identify the task errors and related system inadequacies that contributed to the accident occurrence. Within the U.S. Army, crew error aviation accidents have been attributed to one of five reasons: individual failure (41%), leader failure (27%), standards failure (15%), training failure (12%), or other failure (5%).

This study describes the most frequently occurring aircrew task errors and associated problem areas causing U.S. Army rotary wing accidents from FY 84 through FY 91. A total of 554 accidents occurred, resulting from 906 aircrew errors. The three most frequently occurring task errors involved improper decision, improper attention, and inadequate communication. Together, they accounted for one half of the total number of identified errors. The most frequently reported problem areas were inadequate crew coordination and improper scanning, which accounted for almost 40% of the errors. There were minor differences noted for problem areas based on aircraft type, time of occurrence, and responsible aircrew member. The U.S. Army Aviation Center has introduced corrective measures that address these problem areas. If successful, these corrective measures should reduce crew error, resulting in fewer accidents and a savings in personnel and equipment.

1. INTRODUCTION

U.S. Army Safety Center (USASC) statistics have shown that human error has been a causal factor in approximately 80% of Army aviation accidents. Human error is defined as job performance which deviated from that required by the operational situation (1). Explaining how a human error occurs requires identification of the specific task or function the individual was performing, an explanation of how that task or function was improperly performed, and a statement of how the error caused or contributed to the accident.

The focus of an accident investigation should be to identify the system elements that caused or permitted the accident to occur. The procedure used by the U.S. Army to identify and describe errors, material failures, environmental factors, inadequate system elements and recommendations is called the "3W approach." This approach requires the investigator to answer three questions:

a. *What happened?* Identify how the accident occurred. Identify key factor(s) (task errors) that contributed to the accident occurrence.

Standards Failure	Standards/procedures are not clear or practical, or do not exist.
Training Failure	Individual not trained to known standard (insufficient, incorrect or no training on task).
Leader Failure	Leader does not enforce known standards.
Individual Failure	Individual knows and is trained to standard but elects not to follow standard (self discipline).
Other	Equipment/material improperly designed/not provided; inadequate maintenance/facilities/ services.

Figure 1. Sources of human error

b. *What caused it?* Identify the inadequate system element(s) that caused or permitted the accident to occur.

c. *What to do about it?* Identify remedial measures that will correct the system inadequacy.

In human-error accidents, the error causing the accident usually can be traced to one of four sources: lack of established standards or procedures, lack of training, failure to enforce standards, or individual failure to follow standards (figure 1). In essence, when standards/ procedures are not clear or practical or do not exist and the aircrew member makes an error, that error is the result of a standards failure. If the standards exist, but aircrew members are insufficiently, incorrectly, or not trained to known standards, the error is a result of training failure. If leaders fail to enforce existing standards, human error is the result of leader failure. And finally, when standards are known by aircrew but are not followed, then the source is individual failure. Within the U.S. Army, individual failure accounts for 41% of all human error aviation accidents, while leader, training and standards failure account for 27%, 12%, and 15% respectively. The remaining 5% is attributed to equipment or material improperly designed or not provided; or inadequate maintenance, facilities or services.

Recent USASC studies (2,3) have identified a list of problem areas associated with operational issues. Problem areas, as defined here, refer to the manner in which system deficiencies and associated task errors are manifested in aviation operations. Systematic identification of specific problem areas frequently associated with human-error accidents provides valuable information for the development of recommendations to correct these areas. This research was conducted to identify the most frequently occurring aircrew task errors and associated problem areas causing U.S. Army rotary wing accidents. Recommendations to reduce specific problems could then be made, resulting in fewer accidents and a savings in personnel and equipment.

2. METHODS

All Class A through Class C U.S. Army rotary wing accidents attributed to aircrew error, inclusive of Fiscal Year (FY) 84 through FY 91 were reviewed for this study. This classification includes accidents resulting in at least total property damage of $10,000 or an injury that causes any loss of time from work beyond the day on which the accident occurred (4). The narrative reports for each accident were systematically reviewed to verify that aircrew error was a cause factor in each accident, identify the specific task error(s), and identify the associated problem area(s).

The task error(s) for each accident were identified from the standard taxonomy currently in use at the USASC (Annex A). The associated problem area was then identified for each task error. The set of problem areas used for this study is based on previous research conducted at the USASC (2,3), and is presented in Annex B.

Specific information, to include aircraft type, period of day and duty position of crewmember making the task error were collected for each accident case. Matrices were developed for each variable, which displayed the frequency of task errors and associated problem areas, and a computerized database is being constructed to allow future analysis.

3. RESULTS

These data are considered preliminary and therefore subject to change based on future in-depth analysis. Of the 626 human error accidents analyzed, 72 cases (11%) were excluded from the study. Reasons for rejection included no supporting evidence for human error even though the cases were coded as human error in the data base, human error attributed to non-crewmember personnel, flight-related accidents not associated with aircrew error, and insufficient information. The remaining 554 cases accounted for 906 total aircrew errors. In terms of lost manpower and equipment, these accidents resulted in 189 fatalities and 491 injuries, at a cost of over $560 million to the U.S. Army.

All 8 of the problem areas and 13 of the 14 task errors were cited in the study. The distribution of task errors is shown in Table 1. The three most frequently occurring errors: improper decision (n=178), improper attention (n=160), and inadequate communication (n=116) accounted for 50% of the total errors.

The distribution of problem areas is presented in Table 2. Two categories, inadequate aircrew coordination (n=167) and improper scanning (n=166), accounted for almost 40% of the errors. Improper attention was the task error cited as

Table 1. Distribution of task errors

Task Error	Number	% of Total
Improper decision	178	19.6
Improper attention	160	17.7
Inadequate communication	116	12.8
Failed to follow procedures	110	12.1
Inadequate inspection	77	8.5
Misjudged	73	8.1
Failed to recognize	55	6.1
Failed to anticipate	45	5.0
Inadequate planning	37	4.1
Improper complex action	22	2.4
Misinterpreted	16	1.8
Failed to follow principles	12	1.3
Inadequate improvising	5	0.5
Total	**906**	**100.0**

Table 2. Distribution of problem areas

Problem Area	Number	% of Total
Coordinate	167	18.4
Scan	166	18.3
Diagnose/respond to emergency	129	14.3
Detect	112	12.4
Plan-during flight	109	12.0
Plan-preflight	80	8.8
Estimate	68	7.5
Maintain/recover orientation	51	5.6
Other	24	2.7
Total	**906**	**100.0**

the most frequent cause for improper scanning and inadequate communication the most frequent error associated with aircrew coordination problems.

Problem areas were similar for all aircraft types with a few exceptions(Table 3). A substantially larger percentage of scanning problems were identified in AH-64 aircrew members. In contrast, very few AH-64 and CH-47 crews were noted to have a problem in diagnosing or responding to an actual, simulated or perceived emergency. Scanning was the most frequent problem identified in observation and attack aircraft (AH-1, AH-64, OH-58, AH/OH-6) while aircrew coordination was most frequently cited for utility and cargo helicopters (UH-1, UH-60, CH-47).

The distribution of problem areas according to the period of the day in which the accident occurred is depicted in Table 4. The improper identification of or response to an

Table 3. Percent distribution of problem area by aircraft type

Problem Area	UH-1 (N=226)	UH-60 (N=150)	OH-58 (N=183)	AH-1 (N=153)	AH-64 (N=77)	AH/OH-6 (N=54)	CH-47 (N=50)	Other (N=13)
	AIRCRAFT TYPE							
Coordinate	18.1	24.7	14.8	11.8	22.1	14.8	22.0	7.7
Scan	9.7	17.3	16.8	22.2	38.9	22.2	16.0	23.1
Diagnose/respond to emergency	20.4	6.0	15.9	17.0	1.3	20.4	2.0	53.8
Detect	10.2	14.0	14.2	11.1	9.1	9.3	24.0	0.0
Plan-during flight	14.2	12.0	13.7	10.4	9.1	14.8	4.0	7.7
Plan-preflight	10.2	9.3	6.0	11.8	2.6	5.5	16.0	7.7
Estimate	5.3	6.0	10.4	8.5	6.5	11.1	8.0	0.0
Maintain/recover orientation	7.5	8.0	5.5	3.9	5.2	0.0	4.0	0.0
Other	4.4	2.7	2.7	3.3	5.2	1.9	4.0	0.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 4. Percent distribution of problem areas by time of occurrence

Problem Area	Day (N=549)	Night (N=357)
Coordinate	15.5	23.0
Scan	16.4	21.3
Diagnose/respond to emergency	19.1	6.7
Detect	12.4	12.3
Plan-during flight	14.7	7.9
Plan-preflight	9.3	8.1
Estimate	8.2	6.4
Maintain/recover orientation	0.9	12.9
Other	3.5	1.4
Total	**100**	**100.0**

emergency was the most frequently reported daytime problem, while scanning and crew coordination problems were most often cited at night. In addition, a significantly larger percentage of aircrew members failed to maintain or recover orientation at night as compared to day.

The duty position of the aircrew member making the task error was also evaluated (Table 5). Among the study population, approximately 3 out of every 5 task errors were caused by the designated pilot. Copilot and instructor pilot errors each accounted for an additional 17%. Improper scanning and poor crew coordination were the most frequent problems noted for pilots and copilots, while improper identification of, or response to an emergency was the problem most frequently cited for instructor pilots and student pilots. Over half of all problem areas attributed to crew chiefs were due to a failure to detect hazards.

Table 5. Percent distribution of problem areas by crewmember committing error

Problem Area	Pilot (N=536)	Copilot (N=160)	Instructor Pilot (N=150)	Student Pilot (N=22)	Crew Chief (N=15)	Other (N=23)
	CREWMEMBER					
Coordinate	16.8	23.1	20.0	4.5	33.3	17.4
Scan	18.7	20.0	18.0	13.6	6.7	0.0
Diagnose/respond to emergency	13.3	11.3	20.7	36.4	0.0	4.3
Detect	11.4	14.4	8.7	4.5	60.0	21.7
Plan-during flight	14.4	6.9	11.3	0.0	0.0	17.4
Plan-preflight	14.4	6.9	11.3	0.0	0.0	17.4
Estimate	8.6	5.6	6.7	9.1	0.0	4.4
Maintain/recover orientation	5.8	6.2	5.3	4.6	0.0	4.4
Other	0.9	6.3	2.6	22.7	0.0	0.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

4. DISCUSSION

The purpose of this study was to identify and analyze the most common problem areas associated with aircrew error. There were two dominant problem areas: improper scanning and poor aircrew coordination. Similar findings were noted in a previous USASC study (5), where these two problem areas accounted for 46% of the total number of errors involved in the top 15 violated rotary wing procedures.

Scanning problems may be categorized as either fixated, limited, or improper technique (5). A fixated scan occurs when a crewmember discontinues head and eye movement when searching his field of view. Limited scans refer to searching only a portion of the field of view, while improper technique refers to scanning too close in, too far out, too fast, or too slow. Within this study, scanning problems occurred more frequently in aircraft with tandem seating (AH-1, AH-64) where the forward field of view is restricted for the backseat pilot. In addition, scanning problems were cited more often at night. This may be attributed to degraded visual function and reduced visual cues (6), combined with visual limitations of night vision devices (7) frequently used during night flight.

The large number of scanning problems identified in AH-64 crews (39%) warrants further consideration. Visual input is provided to crew members through the use of the integrated helmet and display sight system (IHADSS), which is unique to this aircraft (8). When flying the AH-64 at night, the pilot night vision system (PNVS) provides a field of view restricted to a 30x40-degree box (9). Head movement is limited to 90 degrees left and right, so one cannot look to the rear at all. In addition, the PNVS sensor is located on the nose of the aircraft, which displaces the eye point by 8 to 10 feet in front of the pilot and creates some difficulty with motion parallax. Pilots have also reported effects of binocular rivalry, resulting in an unusable visual image or periodic closing of the left eye to clear the problem.

Aircrew coordination failures were identified in all types of aircraft for all aircrew members. Based on the crew member distribution of failures (17% for instructor pilots versus 1% for student pilots), poor crew coordination was not due to inexperience. The most frequently cited reason for this problem (33% of the crew coordination failures) involved non-flying crew members failing to provide needed assistance or information to the flying crew member. When flying at night, there is even less margin for crew error, which further exposes crew coordination weaknesses. As a result, poor aircrew coordination accounted for 23% of the total night related problems.

Crew errors are related to basic aviator skills and persist due to inadequate training, procedures, leadership, and individual self discipline. These critical skills and techniques must be identified and formally integrated into training and standards. The U.S. Army Aviation Center has instituted changes to its written procedures and training methods relating to crew coordination and proper scanning techniques. In addition, TC 1-210, *Aircrew Training Manual (ATM) Commander's Guide*, and TC 1-214, *ATM Attack Helicopter, AH-64*, have both been revised to incorporate crew coordination requirements into the training plan and individual ATM tasks. These same requirements are to be incorporated into the planned revision of all ATMs.

Further actions by the USASC have included a new appendix for Army TC 1-204, *Night Flight Techniques*, dealing with crew coordination and scanning during night vision goggle (NVG) operations in the desert; and a night crew error training video. These corrective actions should help to reduce crew error, resulting in fewer accidents and a savings in personnel and equipment.

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ANNEX A

TASK ERRORS

1. **Inadequate inspection/search.** Failure to properly look, listen, or feel in different locations for something, not knowing if, where or when it may occur.
Key words: locate, read, detect, observe.

2. **Improper attention.** Failure to pay attention to one or more activities or operations.
Key words: divide attention, monitor, scan, survey, time share, or watch.

3. **Failed to recognize.** Failure to determine what something is and what its characteristics are so it can be distinguished from other things that are similar.
Key words: identify, discriminate, or distinguish.

4. **Misjudged clearance/speed/weight/size/distance.** Improper evaluation of size, weight, temperature, movement, direction, distance or sound of things seen, heard, or felt without the use of measurement devices.
Key words: compare, estimate, or evaluate.

5. **Misinterpreted.** Failure to properly apply logic, rules, or computational steps to information so it can be correctly interpreted and used in performing the task at hand.
Key words: calculate, categorize, code, compute, itemize, process, tabulate, or translate.

6. **Failed to anticipate.** Failure to expect immediately upcoming events (short-term planning) to be prepared to act or react accordingly.
Key words: expect, for see, prepare for.

7. **Inadequate planning.** Failure to properly organize actions and plan for future job needs.
Key words: allocate, assign, coordinate, direct, organize, or schedule.

8. **Improper decision.** Selection of an improper course of action when–
   a. The best choice could be made using available information.
   b. The best choice could be carried out using available resources, and/or
   c. One rule, principle, or procedure for deciding the course of action clearly applied.

Key words: choose, determine, analyze, elect, or select.

9. **Inadequate improvising/troubleshooting/problem solving.** *Failure to devise a workable course of action when–*
   a. The best course of action could not be decided using available information.
   b. The best course of action could not be carried out using available resources, and/or
   c. One rule, principle, or procedure for deciding the course of action did not clearly apply.

Key words: adapt, devise, fabricate, or invent.

10. **Failed to follow procedures/orders/laws.** Failure to use the proper written or verbal instruction as specific guidance in performing a task.
Key words: carry out or execute.

11. **Failed to comply with general rules/principles.** Failure to use the rule, principle, or commonly accepted practice as general guidance in performing a task.
Key words: comply with or obey.

12. **Improper simple physical action.** Improper performance of separate simple movements made with a certain purpose in mind; e.g., completing job, task, or part of a task.
Key words: lift, hold, drop, hit, push, pull, sit, stand, reach for, open, close, connect, disconnect, activate, press, turn, grasp, grip, set, or start.

13. **Improper complex physical action.** Improper performance of action(s) involving coordinated movements to which continuous adjustments are made based on information related to the task at hand.
Key words: walk, run, crawl, climb, carry, jump, align, adjust, steer, brake, aim, accelerate, swim, throw, or track.

14. **Inadequate communication.** Failure to convey facts, instructions, or directives required to perform a task by speaking, writing, signaling, or otherwise giving information to be acted on.
Key words: ask, answer, signal, inform, advise, direct, indicate, instruct, request, speak, transmit, or write.

ANNEX B

PROBLEM AREA DEFINITIONS

1. **Scan.** Improper direction of visual attention inside or outside the aircraft; i.e., too much or too little time on one object/area; scan pattern not thorough or systematic.

2. **Maintain/recover orientation.** Failure to properly execute procedure(s) necessary to maintain or recover orientation in flight environments known to restrict visibility; e.g., snow, dust, IMC, black hole, and over black water.

3. **Plan–during flight.** Improper inflight modification of flight plan or failure to properly modify flight plan in response to unanticipated events or conditions.

4. **Plan–preflight.** Failure to choose appropriate flight options for known conditions and contingencies and develop these into a course of action to maximize probability of mission accomplishment.

5. **Estimate.** Inaccurate estimation of distance between objects or rate of closure with objects.

6. **Detect.** Not identifying obstacles or recognizing other hazardous conditions; e.g., obstacles in landing area, unsecured equipment and improper control/switch position.

7. **Diagnose/respond to emergency.** Improper identification of or response to an actual, simulated, or perceived emergency.

8. **Coordinate.** Failure of crewmembers to properly interact (communicate) and act (sequence and timing) in performance of flight tasks.
   a. *Direct assistance* - Failure to properly direct assistance from non-flying crewmembers; e.g., provide information on airspeed, altitude, engine; or assist with aircraft clearance and control.
   b. *Announce decision* - Failure to announce decision or action that affects other crewmember's duties.
   c. *Positive communication* - Lack of positive communication (transmission, acknowledgment, confirmation) using standard terminology with specific qualifiers.
   d. *Assign responsibilities* - Failure of PIC to properly assign responsibilities (crew brief or during mission).
   e. *Offer assistance* - Failure to offer assistance or information requested or needed by the pilot on controls.
   f. *Action sequence* - Improper sequencing or timing of actions.

EPIDEMIOLOGY OF UNITED STATES AIR FORCE SPATIAL DISORIENTATION ACCIDENTS: 1990-1991

by

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SUMMARY

Spatial disorientation (SD) continues to be a contributing factor to a fairly constant proportion of military aircraft accidents. The United States Air Force (USAF) fielded a new accident investigation reporting form in July 1989, which for the first time specified SD Type I, Type II, and Type III as possible causes of aircraft accidents. Of a total of 91 major accidents that occurred over the 2-year period beginning in October 1989, SD contributed significantly to 13 (14%). Although this percentage is higher than that reported in previous studies, the actual rate of SD accidents per 100,000 flying hours (.1843) is lower than previously reported. Type I SD was the cause of all 13 accidents; 9 of the 13 were fatal; 6 occurred in night or instrument meteorologic conditions (IMC) conditions; and 11 involved cockpit attention problems, such as inattention, distraction, or channelized attention. Pilot inexperience did not appear to be a factor: average total flying time for the 13 pilots was 1,687 hours. Coding for SD on accident investigation reporting forms was not consistent. There were both individual differences between flight surgeons, differences between flight surgeons and pilots, and trends in reporting overtime. There is, however, a consensus that SD represents a major problem in military aviation. A scientific approach to this important problem would be facilitated if agreement could be reached on defintional and semantic issues.

INTRODUCTION

The number of accidents caused by SD has been determined (see Table II) for several flying populations over the past four decades (1-7). All known studies have used the results of accident investigation boards as a basis for categorizing SD accidents. Examination of the potential for misclassification resulting from the accident reporting process has been noticeably lacking. Only one report critically examines potential semantic difficulties with the definition of SD (6). A knowledge of the history of SD is essential for rationally interpreting reported SD rates.

The understanding of SD has changed dramatically over the past 60 years. The existence of SD was first proved in 1926 by Major William C. Ocker (8). Ocker made the crucial discovery during a routine semiannual physical examination performed by a flight surgeon, Capt David Meyers. During the examination, Ocker was blindfolded and rotated in a Barany chair--a technique used to find possible vestibular (inner-ear balance organ) pathology. While rotating blindfolded and not being able to identify correctly the direction of turn, Ocker suddenly realized why pilots were having problems when flying in clouds and fog. His realization was the first recognition of the phenomenon subsequently referred to as "pilot vertigo," and now called spatial disorientation. This phenomenon, he now understood, was a result of inadequacy of the vestibular sensory system.

In spite of Ocker's finding, many pilots refused to accept the fact that spatially orienting instruments were necessary. Pilots were generally taught to develop a "feel for the ship," the antithesis of reliance on instruments. Their understanding of SD would remain primitive--i.e., that it was a weakness of the pilot's innate ability to fly an airplane. Well into the 1940s instrument training manuals illustrated a somewhat limited understanding of SD, and emphasized only vestibular conflicts (e.g., the following excerpt from Instrument Flying--Basic, 1943) (9):

> "... What to do about these sensations:
> (3) Shake your head and move your body around...
> (4) If you feel that the aircraft is banked in one direction, although it actually is level, try banking in the opposite direction..."

In 1961, the term "vertigo," rather than "SD," was still primarily used in American textbooks of aerospace medicine and predominantly vestibular illusions were discussed (10). A decade later the updated edition of the same textbook discussed a range of both vestibular and visual illusions under the heading of "Spatial Disorientation" (11).

As early as 1958, the scientific literature began to identify visual cues external to the cockpit as possible sources of SD (12). It was understood that if conflicts between the visual scene and the cockpit flight instruments were not recognized and properly resolved, SD could result. Head-up displays on the fighter aircraft of the 1970s and 1980s enabled pilots to spend more time with their eyes out of the cockpit, and thus to increase their chances experiencing visually induced forms of SD at night or in instrument weather conditions. By 1985 aeromedical textbooks included expanded discussions of visual illusions and sensory mismatch in an effort to improve the understanding of SD (13).

Just as our understanding of the causes and mechanisms of SD has matured from 1926 to the present, so has the definition of SD evolved. The lack of a generally accepted definition of SD has hampered aircraft mishap investigators by depriving them of the ability or motivation to correctly identify SD as the cause of accidents. SD has usually been taken to mean the experiencing of an orientational illusion in flight (13). As a result, unless a specific vestibular or visual illusion was identifiable as having precipitated a mishap, investigators were disinclined to state that SD was a causal factor. One accident investigation board even refused to categorize a Class A mishap as SD-related because of a sentence in a training manual that stated SD was not possible when the natural horizon was visible (14). The document was rewritten in 1986 (15).

What was needed was a definition of SD that incorporates the idea of the pilots lack of a correct awareness of the aircraft state, regardless of the specific illusion responsible. An attempt at such a definition was "a state characterized by an erroneous sense of one's position and motion relative to the plane of the earth's surface" (16). But even this comprehensive definition lacks utility in that it does not specifically identify those positions and motion parameters that pilots must monitor to keep their aircraft from crashing as a result of illusory orientational cues and consequent misdirected control inputs. Accordingly an "operational" definition of SD has proposed by USAF Armstrong Laboratory personnel and used successfully in consultations supporting aircrft mishap investigations. This operational definition of SD is "a state characterized by a pilot's erroneous percept of the magnitude or direction of any aircraft <u>control</u> or <u>performance</u> flight parameter," or articulated even more clearly for pilots, "an erroneous sense of any of the flight parameters displayed by aircraft control and performance instruments" (16). As flight instruments are divided according to function into control, performance, and navigation categories (15) and the control and performance categories contain the co-called "primary" flight instruments needed to monitor aircraft state, it is logical to define SD in terms of control and performance parameters or instruments. By this definition, a pliot who incorrectly perceives his/her pitch or bank attitude (control parameters), or vertical velority, altitude, turn rate, etc. (performance parameters), is considered to be spatially disoriented, whatever the visual or vestibular mechanism responsible for the incorrect perception.Even though this latest definition has been received quite favorably, the understanding of SD in such terms is at present by no means universal.

Not only have our understanding of SD and the definition of SD changed, but so has our way of recording the accident data. Until 1989, the USAF accident reporting form (Air Force Form 711gA), gave the investigating flight surgeon the choice of attributing accident causation to either "visual illusion" or "disorientation/vertigo," and he could rank the importance of this factor as "definitely contributed," "suspected factor," or "... present but did not contribute..." (see Fig 1a). Beginning in July 1989, a new accident reporting form was adopted which allowed the flight surgeon specifically to choose SD Type I, SD Type II, or SD Type III and rate the significance of the SD contribution to the accident on a 0 to 4 scale (see Fig 1b).

This paper attempts to determine the current rate of SD in the USAF by an in-depth assessment of Class A mishaps. In addition, the paper investigates how reported rates have been influenced historically by an improved understanding of SD, definitional/semantic changes, and altered methods of reporting SD.

MATERIALS AND METHODS

The life sciences data base of the USAF Inspection and Safety Center was reviewed for the years 1980-1991. Data were separated by fiscal year (FY) (1 Oct-30 Sept). For FY80 through FY89, Class A accidents (major accidents), either "suspected" or "definitely" caused by "disorientation/vertigo" were selected. Major accidents are defined as those resulting in either a loss of life or more than $200,000 worth of damage until 1982; from 1982 until 1989, the damage crierion for a major accident was raised to $500,000. For FY90 and FY91, accidents caused by SD Type I, Type II, or Type III, with the significance of the factor rated 3 or 4 on a scale 0-4, of were chosen. Also, after 1989, the damage criterion for a major accident was raised to $1,000,000.

The total number of Class A mishaps, and the total flying time for all aircraft for each fiscal year, were used to determine the proportion of accidents caused by SD, and the rate of occurrence of SD accidents, respectively. Past flying-hour data (available back to 1921) were used to calculate rates for the data presented by Barnum and Bonner (1958-1968) in Table I. USAF Inspection and Safety Center codes that categorize accidents according to natural groupings, rather than causality, were also used to investigate secular trends in the categorization of USAF SD mishaps (Table III).

Accident reports for those accidents attributed to operator error during the four-year period FY88-91 were reviewed by two of the investigators (TL and WE) in an attempt to verify the classifications of these accidents. For some accidents, however, the investigators did not agree between themselves on the appropriate classification. Therefore, only the codings determined by the original accident investigation board were used. Accidents attributed to SD after implementation of the new accident reporting form in FY90 appeared to represent a different subset of accidents from those attributed to SD when the old form was used. Therefore, detailed analysis of SD accidents was done only for FY90 and FY91. For these years the actual accident records were reviewed to determine the nature of the SD accidents (Table IV), coexisting perceptual and situational awareness factors (Table V), and personal characteristics and habits of the pilots (Table VI).

Normative data for personal and physiologic variables were obtained from a variety of sources. Age, total flying time, and aircraft-specific flying times were obtained from Military Personnel Center records maintained by the USAF Armstrong Laboratory Human Resources Directorate. Data as of 31 December 1989 were used for all pilots who had flown an F-16, F-15, A-10, or A-7 within the previous 6 months. Using data from the USAFSAM Coronary Artery Risk Evaluation file, we determined that only 6% of the pilot population smoked in 1988.

RESULTS

The proportion of accidents attributed to SD in the USAF appears to have increased slightly over the past four decades while the actual rate of SD has decreased somewhat (Table I). The conditions under which SD accidents occurred varied somewhat depending on the flying population studied (Table II).

Table III gives a breakdown by year of the types of accidents attributed to SD. A comparison of SD categorization before (FY86-FY89) and after (FY90-FY91) implementation of the new accident investigation reporting form revealed an increased tendency to categorize collision with the ground (non-range) accidents during low-level navigation as due to SD on the new form. On the other hand, there was a decreased tendency to categorize pilot-induced control loss accidents as due to as SD on the new form. Most reports of such control-loss accidents attributed to SD had no discussion of SD or of specific vestibular or visual illusions in the narrative. One such accident, for example, involved a pilot who was confused as a result of G-induced loss of consciousness (G-LOC) during aerobatic maneuvering.

Table IV describes the 13 SD mishaps. Most (12/13) of these SD accidents during FY90-FY91 occurred in fighter aircraft and most (9/13) were fatal. All were reported to be Type I (unrecognized) SD. In most cases, no specific vestibular or visual illusions were identified as causal (Table V). Most of these accidents (11/13, 85%) had one or more cockpit attention factors coded in addition to SD (Table V). Table VI compares the personal characteristics and habits of the 13 SD pilots with normative data for the USAF.

Accidents occurring during low-level flight in visual meteorologic conditions (VMC) are common, but until recently have not been coded as SD accidents. According to recent Air Force Inspection and Safety Center statistics, at least 25 low- level turning accidents involving fighter/attack aircraft have occurred since 1982 (17). The ingredients were the same in almost all of these mishaps: low attitude, aircraft banked 60 to 80 degrees in a turn, clear weather and good visibility, greater than 1 G on the pilot (2-5.5 G), and pilot looking out of the cockpit for an adversary, a wingman or other object of interest. For an unexplained reason the aircraft overbanked during the turn; and and as a result, the nose sliced toward the ground. It is presumed the pilot was looking somewhere other than off the nose of the aircraft and did not detect the pitch down, and collision with the ground occurred. At least three such accidents occurred during FY88-FY89 and were not coded as SD. In one of these, the investigating flight surgeon demonstrated his lack of understanding of SD by stating that the G-excess illusion could not be a factor at such "low G" levels (90 degree bank) and with "good visual cues." In contrast, during FY90-FY91, four collisions with the ground during low-level flight in VMC and four night-range accidents were attributed to SD. The G-excess illusion was specifically considered by the investigating flight surgeon in several of these seven mishaps.

Misclassification in the reporting process was evident both before and after implementation of the new reporting form in 1989. Accidents were often coded as "other" in evident dissatisfaction with SD codes available with both the new and the old forms. Using the old form, investigating flight surgeons in several cases during FY88-FY89 discussed specific mechanisms of SD but did not code the accidents as "disorientation/vertigo": one case of "oculogravic illusion" was coded as a "visual illusion" but not as "disorientation/vertigo". In three cases, the investigating flight surgeon coded mishaps as "other" instead of using the factors available to choose from on the form; and the descriptions, "visual misperception," "somatogravic illusion," and "disorientation," were added by the flight surgeon. Investigating flight surgeons using the new form also coded accidents in the "other" category three times in FY90-FY91. The terms "spatial misorientation" or "misperception" were substituted for SD.

Misperception of position was coded as a cofactor along with SD in 5 accidents (Table V), and was coded in 5 additional accidents when SD was not coded: 2 mid-air collisions, 1 geographic misorientation, 1 collision with paratroopers, and 1 controlled flight into the ground on the range. Misperception of speed was never coded as a cofactor with SD and was coded without SD being coded in 5 additional mishaps: 2 midair collision accidents, 1 range accident, 1 loss of control accident, and 1 engine stagnation accident. Misperception of distance was coded twice as a cofactor with speed in midair collision accidents. "Visual illusion" was coded on 2 occasions without SD being coded: 1 ground collision with a wingman on takeoff roll and 1 collision with ground following visual flight into IMC. "Visual acquisition" was coded 3 times: all in midair collisions.

DISCUSSION

Our analysis of recent USAF SD accidents is in agreement, in some respects, with other investigators. All investigators agree that SD is a significant cause of aircraft accidents. Our finding that involved pilots were of average experience level (1687h) also agrees with other investigators who found similar total flying times of 1,495 hours (1) and 1,488 hours (3).

In several respects, however, our results were different from those of past investigators. The proportion of USAF accidents caused by SD in FY90 and FY91 (14%) is slightly higher than that previously reported, while the actual rate per 100,000 flying hours (.18) is lower. No SD accidents during FY90 and FY91 occurred during takeoff or landing. Over half of the FY90-FY91 SD accidents occurred in VMC, often during low-level navigation: this increase in the coding of such accidents as SD-related is no doubt due to a change in the definition and understanding of SD by investigating flight surgeons.

The USAF attributes a higher proportion of SD accidents to Type I SD (almost 100%) than does the Navy (only 52%). Discussion with both U. S. Navy Safety and aviation personnel have convinced us that semantic variations account for much of this difference. In addition, some of this difference may be due to misclassification of accidents; for example, we found at least one USAF accident during FY90-FY91 which we would have attributed to SD Type II rather than SD Type I.

Although there is an increasing tendency for flight surgeons to code low-level accidents in VMC as due to SD, pilots do not necessarily concur in this categorization. A survey of 30 USAF pilots in 1990 (Lyons, Thomae, Mittelstaedt, Pierce, Schiffler, and Reid, unreported) found that near-accidents caused by SD are frequent, and that pilots attribute only accidents occurring in obscured visibility to SD. Of the 30 critical incidents described in the survey, 3 were attributed primarily to SD; and in three additional incidents the pilots rated SD as definitely important (5 or 6 on a scale of 6) in contributing to the incidents. Thus, SD contributed significantly to 20% of these near-accidents. Four of these incidents occurred in night IMC; 1 occurred in unspecified IMC; and 1 incident occurred during flight in and out of clouds. Phase of flight was also a factor: 3 of the incidents occurred on instrument approaches, while 2 others occurred during formation flight. Eight additional incidents of near-collision with the ground (6 in VMC and 2 in marginal VMC) were not coded attributed by the pilots to SD.

Definitional problems definitely contribute to the range in the proportion of accidents attributed to SD. This has been suggested by Singh & Navathe, as an explanation for the low proportion of accidents attributed to SD in the Indian Air Force (6). Also, the FAA attributes only 2.5% of all accidents to SD (3rd leading cause), yet FAA statistics do not clarify the relationship of SD to the 2nd leading cause of accidents, "continuing VFR flight into adverse weather." If the actual contribution of SD to the latter accident category were to be made explilcit, the proportion of civilian aircraft accidents attributed to SD would undoubtedly be much higher.

Sound accident epidemiology should be based on a study of actual accident rates rather than proportions of accidents attributed to a given cause. This was illustrated by Table I. Another example of the potential for misapplication of proportion statistics is the apparently lower proportion of accidents attributed to SD by the U. S. Navy (5%) than by the USAF (12%) in FY80-FY89. This lower proportion is entirely due to an overall higher accident rate for the U. S. Navy and the use of different causality criteria in the U. S. Navy statistics. The Bellenkes, et al, study included only accidents with SD as a "definite" cause; whereas the USAF data for FY80-FY89 in Table I also included those in which SD was a "suspected" contributor (3). The actual rates for the U.S. Navy for "definite" SD (.16 per 100,000 flying hours) and for "possible," "probable," and "definite" SD (.53) are actually higher than the corresponding USAF rates for "definite" contributor (.11) and "suspected" and "definite" contributor (.24).

The distinction between accidents caused by inadequate cockpit attention/task management or other forms of loss of situational awareness (LSA) and accidents caused by SD is not clear. Recently, investigators have lumped LSA related accidents with SD into one large LSA/SD category (18). It is true that most SD accidents have such cockpit attention deficits, and that some attention-deficit accidents involve the element of SD in the mishap sequence. Such categorization, however, results in lumping 270 (76%) of the 356 total operations-factor accidents from FY80 through FY89 into one category.

In conclusion, coding for SD on accident investigation reporting forms is not consistent. There are individual differences in knowledge and perspective between the flight surgeons who investigate mishaps, differences between these flight surgeons and the pilots who work with them on accident investigating boards, and differences in reporting and coding policies over time. There is a consensus that SD represents a major problem in military aviation. A scientific approach to this important problem would be facilitated if agreement could be reached on definitional and semantic issues.

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ID ENVIRONMENTAL FACTORS

PHASES OF MISHAP
A - ACCIDENT
E - ESCAPE
L - LANDING
S - SURVIVAL *(Includes parachute landings)*
R - RESCUE

FACTOR IMPORTANCE
D - DEFINITELY CONTRIBUTED
S - SUSPECTED FACTOR
P - CONDITION PRESENT, BUT DID NOT CONTRIBUTE TO ACCIDENT OR INJURY.

FACTORS		A	E	L	S	R
VISUAL ILLUSIONS	613					
UNCONSCIOUSNESS	614					
DISORIENTATION/VERTIGO	615					
HYPOXIA	616					

Fig. 1a. Excerpt from AF FORM 711gA, Sep 76

2 SENSORY AND PERCEPTUAL

115 ___ VISION DEFICIT
116 ___ VISUAL ACQUISITION
117 ___ VISUAL ILLUSION
118 ___ VESTIBULAR ILLUSION
119 ___ KINESTHETIC ILLUSION
120 ___ AUDITORY CUES
121 ___ NOISE INTERFERENCE
122 ___ VIBRATION
123 ___ MISPERCEPTION OF SPEED
124 ___ MISPERCEPTION OF DISTANCE
125 ___ MISPERCEPTION OF POSITION
126 ___ SPATIAL DISORIENTATION (TYPE 1) UNRECOGNIZED
127 ___ SPATIAL DISORIENTATION (TYPE 2) RECOGNIZED
128 ___ SPATIAL DISORIENTATION (TYPE 3) UNCONTROLLABLE
129 ___ OTHER

Evaluate each factor for **presence** and the **significance** of its contribution. Mark **PRESENT** Factors with either **0, 1, 2, 3, or 4** from contribution scale. If Factor **NOT PRESENT** leave blank, if **UNKNOWN** if factor PRESENT mark with "U".

NONE 0 —— 1 —— 2 —— 3 —— 4 DEFINITE

DISCUSS PRESENT FACTORS IN THE HUMAN FACTORS PORTION OF THE NARRATIVE

Fig 1b. Excerpt from AF FORM 711gA, Aug 89

TABLE I. The number, proportion, and rate of USAF accidents caused by SD for four consecutive time periods.

Years	Total Accidents	SD Accidents	Proportion of Total Accidents	Total Flying Hours	Rate per 100,000 Flying Hours
1958-68	4,679*	281*	6%*	79,494,987	.35***
1980-87	524**	61**	12%	26,898,849	.23***
1988-89	109	13	12%	6,749,640	.19***
1990-91	91	13	14%	7,050,521	.18***

*From Barnum and Bonner (1)

**From Air Force Inspection and Safety Center

***The overall rate for FY80-FY91 is .21 per 100,000 flying hours. One sided binomial probability of this decrease in rate from 1958-1968 to FY80-FY91 occuring by chance = .001.

TABLE II. The proportion of all accidents caused by SD, and the proportion of SD accidents occurring during approach, landing, takeoff, in IMC conditions, and at night, as reported for various flying populations.

		SD Accidents Occurring During Specific Conditions		
Author	SD Accidents As % of all accidents	Approach, landing, or takeoff	IMC	Night
Barnum & Bonner (U. S. Air Force 1958-68)	6%	37%		
Moser (Air Defense Command) U. S. Air Force 1964-67)	9%		64%	73%
Kirkham (U. S. Civilian) 1968-75)	2.5%	89%	68%	26%
Bellenkes et al. (U. S. Navy 1980-89)	5%	39%		48%
Vyrnwy-Jones (U. S. Army 1980-87)	14%	43%		55%
Singh & Navathe (Indian Air Force 1980-87)	2.5%			
Lyons et al. (U. S. Air Force 1990-91)	14%	15%	23%	38%

TABLE III. The proportion of each type of operations-factor mishap caused by SD. USAF Inspection and Safety Center coding for each type of accident is in parentheses. Numerator is the number of such accidents attributed to SD. Denominator is total number of such accidents.

	FY86	FY87	FY88	FY89	FY90	FY91
Collision with Ground (Non-Range)						
- Low-level navigation (C20)	0/2	0/2	0/5	1/5	3/3	1/3
- Approach/Descent (C18,C19)	0/0	1/4	1/2	1/6	0/2	2/3
- Formation (C21)	0/0	2/2	0/1	1/1	1/1	1/1
- VFR in IMC Condition (C23)	0/0	1/1	1/1	1/1	0/1	0/0
- Aerobatics (CC)	1/2	1/2	1/4	0/1	0/1	1/1
Collision with Ground Range (D)	1/2	3/3	0/1	0/0	2/3	2/2
Pilot-induced Control Loss (B)	1/9	3/9	2/7	3/8	0/6	0/4
Midair Collision (E)	0/7	0/4	0/3	0/1	0/7	0/2
Pilot-induced Takeoff and Landing (L,M)	0/4	0/2	0/4	1/8	0/3	0/1
Other	1/4	0/1	0/2	0/3	0/2	0/2
All operations factor mishaps	4/30	11/30	5/30	8/34	6/29	7/19

TABLE IV. Nature of 13 SD Accidents Occuring During FY90-FY91

Crew	
Single Seat	6/13 (46%)
Dual Seat	6/13 (46%)
Multiplace	1/13 (8%)
Fatal	9/13 (69%)
Conditions - IMC	1/13 (8%)
Night	3/13 (23%)
Night/IMC	2/13 (15%)
Fall	4/13 (31%)
Winter	2/13 (15%)
Spring	5/13 (38%)
Summer	2/13 (15%)
Type of SD	
Type I (unrecognized)	13/13 (100%)
Type II (recognized)	0/0 (0%)
Type III (incapacitating)	0/0 (0%)*

*One accident reported on the new 711gA in late FY89 was coded as SD Type III.

TABLE V. Sensory/Perceptual and Situational Awareness Cofactors of SD Accidents Occuring during FY90-FY91.

Sensory/ perceptual factors coded	- Misperception of Position	5/13	(38%)
	- Vestibular Illusion	5/13	(38%)
	- Visual Illusion	2/13	(15%)
	- Kinesthetic Illusion	1/13	(8%)
	- Auditory Cues Deficient	1/13	(8%)
	- Misperception of Distance	1/13	(8%)
Situational awareness factors coded	- Selective Inattention	4/13	(31%)
	- Channelized Attention	10/13	(77%)
	- Distraction	5/13	(38%)

TABLE VI. Personal Characteristics and Habits of Pilots Involved in SD Accidents in FY90-FY91.

	Mean (range) for 13 SD Pilots		Mean for USAF Fighter Pilots
Age (years)	33	(27-41)	33
Total Flying Time (h)	1,687	(440-2,965)	1,839
Aircraft Specific Flying Time (h)	635	(219-1,679)	778
Time Since Last Meal (h)	5.6**	(2.6-13)	—
Time Since Last Slept (h)	7.2*	(3.5-14)	—
Duration of Last Sleep (h)	7.3*	(5.8-9)	—
Cigarette Smoker	1/13	(8%)	6%

* Unknown for 1 pilot
** Unknown for 2 pilots

DISORIENTATION AND FLIGHT SAFETY - A SURVEY OF UK ARMY AIRCREW.

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SUMMARY.

This paper reports the findings of a questionnaire survey intended to gather information on the genesis and severity of disorientation. 440 UK Army aircrew were targeted and the response rate was 79%.

The survey confirmed the high incidence of disorientation (24% of aircrew had suffered at least one episode severe enough to have put flight safety at risk at some point during their flying career and 6% had suffered such an episode in the previous 4 months). Only 10% had never suffered any disorientation.

Factors that were particularly provocative of disorientation included Instrument Flying and Night Flying (with and without Night Vision Goggles). Although both were associated with an increased INCIDENCE of disorientation only Night Flying was associated with an increase in SEVERITY (as assessed by the threat to Flight Safety). Episodes during daytime Instrument Flying were LESS severe than those during daytime Visual Flying until cases of the 'leans' were excluded from the analysis, following which the trend was reversed (although only to a marginally significant level). Interestingly, episodes during NVG Flying did not appear to be more severe than those during ordinary Night Flying (except insofar that there was an increased risk of another crewmember being simultaneously disorientated - see below). Other factors relevant to the 'severity' of episodes included weather conditions (such as rain or snow), state of mind (whether bored, tired or distracted), location (with episodes occurring in the Gulf being particularly severe) and crew composition.

Aircraft type had a possible effect since manoeuvres in Gazelle aircraft were more likely to be associated with increased 'severity' of disorientation than were manoeuvres in other aircraft. These findings might be contaminated by confounding factors and should be treated with caution - although they agree with the strong subjective views of the aircrew. In contrast, episodes in Lynx aircraft - particularly at night on NVG - were significantly associated with an increased risk of both crewmembers being disorientated simultaneously. TAKING THE DATA FROM ALL AIRCRAFT TYPES, BOTH CREWMEMBERS WERE DISORIENTATED IN 44% OF ALL EPISODES INVOLVING NVGs.

Aircrew qualifications (including Instrument Rating) were not associated with the severity of episodes suffered - except that episodes involving Aircraft Commanders were more likely to be classed as jeopardising flight safety than episodes involving Co-pilots. Flying experience (in terms of hours) gave a mixed picture which probably reflects a number of conflicting trends.

An analysis of narratives indicated that episodes that were purely vestibular in origin were almost always cases of the 'leans' and tended to be of minor consequence. By contrast, the circumstance most associated with 'severe' disorientation was inadvertent entry into Instrument Meteorological Conditions (IMC) - particularly when it was followed by a recovery to Visual rather than Instrument flight.

Information was also gathered on the incidence of 'Break Off' phenomenon. 16% of aircrew had suffered at least 1 episode at some point of their career - and 3% had suffered to the extent of flight safety being put at risk. Only 1 respondent (0.3%) had suffered to that extent during the previous 4 months - although 4% had suffered to a lesser degree.

Aircrew comments show that they consider spatial disorientation to be a real threat to their safety and are appreciative of the training that they already receive (including the airborne disorientation training sortie). They also believe that the ergonomics of their aircraft are not fully optimised to reduce the risks and assist in recovery. Operators need to be made aware of the incidence of disorientation, the areas where flight safety is most at risk, the influence of current and new equipments, and where the most cost effective solutions lie.

INTRODUCTION.

Until 90 odd years ago nothing in the 3000 million year evolutionary history of Mankind had directly concerned his ability to fly. Instead, his physiology was optimised by natural selection for a 2-dimensional, terrestrial, tropical, low speed and low acceleration existence. It should therefore surprise no-one that humans who take to the air sometimes suffer failures of physiology and perception that leave them confused as to how they or their aircraft are orientated. This, of course, is dangerous, and in the UK Army spatial disorientation (as defined as a failure to correctly determine one's attitude or motion relative to the Earth's surface or its gravitational pull) has historically caused about 15-20% of our accidents and some 30% of our fatalities (1,2).

In an attempt to educate aircrew as to their physiological limits an airborne 'Disorientation Training Sortie' was introduced in the mid 1980's. This, combined with changes in procedures and equipments, has altered circumstances to such a degree that it was considered necessary to carry out an assessment of the present incidence and severity of disorientation episodes. A questionnaire survey was carried out in 1991, with the aim of gathering information on disorientation together with related factors that might be considered provocative or might influence severity or resolution.

In addition, information was sought on the incidence of 'break off' phenomenon. This phenomenon is not true spatial disorientation but is often considered in association with it. It is characterised by feelings of detachment, isolation and unreality. Victims may feel that the aircraft is balanced on a knife edge or - in severe cases - that they are 'looking in on themselves from outside the cockpit'. While associated primarily with long, monotonous, fixed wing flights at high level with poor visual cues, it is not unknown in helicopter aircrew (1,3,4,6,8).

The aim of this part of the survey was to discover the incidence of this anxiety provoking event amongst current Army aircrew. No attempt to relate it to any specific factors was planned.

METHODS.

Subjects.

A 10 sided questionnaire was posted to 440 Army aircrew. Full confidentiality was promised but the names of respondents were requested so that answers could be clarified and so that non-responders could be followed up. If no clarification was required the name of the respondent on the completed questionnaire was destroyed.

Subjects were selected from a list of Army aircrew provided by the postings branch. They were not stratified by rank, age or qualification, and they were representative of Army aircrew as a whole.

The Questionnaire.

The questionnaire had 5 main parts. The first asked for personal details while the second concerned flying experience, qualifications and currency.

The third section asked for details about disorientation broken down over 2 periods - the respondent's whole career and the 4 months previous to the survey. For each period, identical and specific questions were asked about the incidence of disorientation and details were sought of the 'worst' episode suffered. Information was requested on aircraft type, equipment in use, sortie type, experience at the time of the episode, flight conditions, flight manoeuvres, crew position, state of health and state of mind. Brief narrative descriptions were requested as well. 'Break off' was specifically excluded (except for a specific request for information on its incidence) as was 'geographical disorientation' (or getting lost). Underlying the whole section were definitions of severity based on flight safety implications:

'MINOR' episodes were those in which flight safety had not been jeopardised.

'SIGNIFICANT' episodes were those in which flight safety had not been jeopardised but in which it might have been put at risk if circumstances had been different (e.g. solo or close to the ground).

'SEVERE' episodes were those in which flight safety had been jeopardised.

These classifications should not be confused with similar SENSATION AND CONTROL BASED classifications devised by Nuttall in 1956 and used since by others (4,5,8).

Also in this section was a request to grade different sortie types and different aircraft types on their likelihood to induce disorientation.

The fourth section concerned current disorientation training (and in particular the airborne sortie) while the fifth section provided a blank sheet of paper for comments on any aspect of disorientation considered important.

RESULTS.

Response Rate.

Following one reminder to non-responders the raw response rate was 79% (total returned = 347). The questionnaire was sent out at a time of turbulence soon after the end of the Gulf War and when 'non-responders' were further followed up it was found that most had a reasonable 'excuse' such as being in hospital, being heavily involved in disciplinary action(!) or not having received the questionnaire. (The 'cooked' response rate therefore came to a staggering 94%. This presumably reflects the seriousness with which aircrew consider such subjects.) In the event, 338 of the returned questionnaires were sufficiently useful for entry into the survey.

Qualifications and Experience of Respondents.

The age of the respondents ranged from 22 to 54 years (mean 33.2, std dev 5.9 and mode 32). 20% of respondents were Qualified Instructors (QHIs), 59% were Aircraft Commanders (Ac Comds) and 22% were Co-Pilots. Total Flying Hours ranged from 79 to 8869 (mean 1903, std dev 1499). Total flying hours in the previous 4 months ranged from 0 (n=11) to 241 (mean 89, std dev 51).

Almost all respondents were Rotary Wing (RW) aircrew (8 were current on both Fixed Wing (FW) and RW aircraft, while 6 were current on FW aircraft only).

Incidence of Disorientation.

Over the whole of the respondents' flying careers:

34 (10%) had never been disorientated.

281 (83%) had suffered at least one 'minor' episode.

188 (56%) had suffered at least one 'significant' episode.

82 (24%) had suffered at least one 'severe' episode.

In the 4 full calender months prior to the survey:

140 (43%) had not suffered even a single episode.

143 (44%) had suffered at least one 'minor' episode.

35 (11%) had suffered at least one 'significant' episode.

16 (5%) had suffered at least one 'severe' episode.

(These figures - which come from section 2 of the questionnaire -are slightly at odds with those that can be derived from section 3 where respondents were asked to describe their worst episode in the previous 4 month period. These figures would show 37 (11%) had suffered a 'significant' episode and 20 (6%) had suffered a 'severe' episode.)

'Worst Ever' and 'Worst in the Past 4 Months' episodes.

There were 308 'Worst Ever' episodes described. (Of these 81 had occurred in the 4 months previous to the survey and were analyzed for most purposes with the '4 month' group in order to avoid events being shared by both groups.) Of the remaining 'Worst Ever' group:

50 (22%) were classed by respondents as 'minor'.

109 (48%) were classed as 'significant'.

68 (30%) were classed as 'severe'.

In the 'Worst Episode in 4 Months' group (total number = 186):

129 (69%) were classed by respondents as 'minor'.

37 (20%) were classed as 'significant'.

20 (11%) were classed as 'severe'.

Some of these '4 Month' episodes were from the Gulf War - stripping these out to produce 'peacetime' figures leaves 125 (38% of non-Gulf aircrew) whose worst episode had been 'minor', 32 (10%) whose worst episode had been 'significant' and 12 (4%) who had suffered a 'severe' episode.

Relevant Factors.

To assess the influence of specified factors on disorientation the severity of the 'worst ever' and 'worst in 4 months' episodes were analyzed against details requested in the questionnaire. For some factors it proved necessary to combine the data from both the 'worst ever' and 'worst in 4 months' groups in order to achieve satisfactory numbers. Unless specified, all probability figures reflect Pearson correlations derived from Chi Squared testing.

Age.

There are several possible factors associated with age that might have an effect on the incidence, severity or subjective assessment of disorientation. For example, older age groups may have flown a wider variety of aircraft under more (or less) challenging conditions. The results below - which are given for the record - should therefore be interpreted with care.

When banded into five year age groups, there was a marginally significant relationship between the age of the respondent at the time he filled in the questionnaire and the severity of his 'Worst Ever' episode ($p=0.049$). Younger respondents were more likely than those who were older to have graded their 'worst ever' episodes as 'significant' and less likely to have graded them 'severe'. The strongest statistical relationship was obtained by breaking the respondents' ages into 2 groups - age 35 or less and age 36 or more ($p=0.00051$). Interestingly, no trends for 'minor' episodes were apparent and when 'severe' and 'significant' episodes were amalgamated all trends disappeared ($p=0.89$).

There was a highly significant relationship between age and the likelihood of reporting disorientation in the previous 4 months. Older age groups were LESS likely to report an episode ($p=0.0034$ for 5 year age bands). However, no significant trend could be established between age and SEVERITY of the worst episode in the previous 4 months ($p=0.748$).

The confounding factors that exist in some of these findings are exemplified by the results of a review of the types of aircraft flown during the 'worst ever' episodes. This showed a highly significant difference for age groups 35 or less and 36 or more ($p=0.00001$) with the older age group quoting a lower frequency of Gazelle and Lynx aircraft and a higher frequency of Scout or 'other military' aircraft. There was NO significant relationship found between age and the type of aircraft quoted in the '4 month' worst episodes.

Flying Hours.

Flying hours and age are closely linked. The mixed picture that appeared for flying hours must be assessed with the same caution used for considering the effects of age. Nonetheless, there were interesting results.

No significant difference in flying experience - in terms of total hours - could be demonstrated between those who had been disorientated at least once and those who stated that they had never been disorientated (mean hours = 1952 and 1882 respectively, T-test $p=0.71$).

The peculiar non-linear relationship between flying experience (in terms of total flying hours) and the severity of the 'worst ever' disorientation episodes is demonstrated in Table 1 - which cites flying experience AT THE TIME OF THE EPISODE against severity. No differences between the 'minor' and 'severe' groups are apparent whereas the intermediate 'SIGNIFICANT' group has a statistically significant LOWER level of experience. (Break down of total flying hours showed that the pattern was no different for night, day and instrument flying.) A similar statistically significant picture was obtained for charting flying experience AT THE TIME OF FILLING IN THE QUESTIONNAIRE against severity of the 'worst ever' episode.

The pattern was NOT repeated, however, for the 'worst episode in the last 4 months' data (Table 2). Here the 'MINOR' group had the GREATEST level of experience, as one might expect. The differences between the 'minor' and the other 2 groups were statistically significant, but although the trend persisted into the 'significant' and 'severe' groups the difference between these was statistically very insignificant (p=0.88).

This last pattern was repeated at a statistically insignificant level when the severity of the 'worst episode in the past 4 months' was analyzed against total career hours. No significant relationship between severity of episode and the total flying hours in the previous 4 months could be demonstrated.

Meteorological Conditions.

Disorientation episodes were much more likely to be 'significant' or 'severe' if they occurred during VISUAL Meteorological Conditions (VMC) rather than during INSTRUMENT Meteorological Conditions (IMC). This surprising result was true of both 'worst ever' episodes and 'worst in 4 months' episodes (p=0.01 and p=0.02 respectively). If cases of the 'leans' were stripped out of the figures, however, the tendency was for IMC to be associated with marginally MORE severe episodes (p=0.082 for the 'combined' data).

This picture of the differences between Instrument Flying (IF) and VMC flying was supported by the responses to a question about outside visual references. Here, episodes suffered during IF (including those 'under the hood') were significantly more likely to be rated as 'minor' in both the 'worst ever' and 'worst in 4 months' groups (p=0.0002 and p=0.003 respectively). Once episodes of the 'leans' were stripped out, no statistically significant differences could be demonstrated (p=0.165 for both groups combined). If light conditions were considered in addition, however, statistical differences did occur - with Instrument Flight at night being associated with increased numbers of 'severe' episodes (see 'light conditions' below).

Although overall episodes occurring during IF were less severe than those occurring in VMC, they appeared to be much more frequent. The 5% of total flying time that respondents had spent on instruments produced 75% of the 'worst ever' episodes. Similarly, 7% of the flying time for the 4 months previous to the survey had been spent on instruments and this produced 80% of the 'worst in the past 4 months' episodes. A number of episodes in both groups were cases of the 'leans' - but removing these still left 17% of all episodes being generated by the 5% of total flying time that had been spent on instruments.

Despite the raised incidence, NO relationship could be demonstrated between the number of hours spent Instrument Flying in the 4 months previous to the survey (whether simulated, actual or both) and the SEVERITY of the worst '4 month' episode.

With regard to other weather conditions, no relationship could be demonstrated between overcast conditions and the severity of 'worst ever' or 'worst in 4 months' episodes (even when the data were combined). For rain, however, the combined groups showed a tendency for rain to be associated with increasing severity of episode (p=0.011). This appeared to be particularly true at night (see 'light conditions' below). There was also a statistically significant relationship between snow effects and increased severity for the 'worst ever' episodes (p=0.012). This could not be repeated in the 'worst in 4 months' data, probably because of lack of numbers (n=3); but when the data were combined the significance was strengthened (p=0.0008).

No increasing severity from episodes associated with going in and out of cloud could be demonstrated, despite a lot of comments from respondents suggesting that they find this particularly provocative.

Light Conditions.

Both 'Worst ever' and 'worst in 4 months' episodes were significantly more serious when they occurred at night (p=0.0002 and p=0.0001 respectively). The pattern appeared the same for both Night Vision Goggle sorties and normal night flying (no significant difference could be shown between the groups, p=0.93). No moon phase effects could be shown during night flying (whether on or off Night Vision Goggles) and no 'into sun' or 'out of sun' effects could be shown during day flying. No 'haze' effects could be shown for any light conditions.

Night flying also appeared to be generally more provocative than day flying in that night flying (non-NVG) accounted for only 7% of total flying hours, but accounted for 26% of 'worst ever' episodes. The figures for NVG are 1% of flying hours and 5% of episodes. These figures are supported by the 'worst in 4 months' results (non-NVG 7% of hours and 12% of episodes, NVG 5% of hours and 17% of episodes). However - as with Instrument Flying - no relationship could be demonstrated between the number of hours spent Night Flying in the previous 4 months (whether on or off Night Vision Goggles) and the SEVERITY of the worst '4 month' episode.

The effect of day/night conditions appeared to spill over into Instrument Flying - daytime IF did not appear to be more provocative than day VMC flying (p=0.42), while night IF had an increased tendency to severity (p=0.015 if episodes of the 'leans' are included, p=0.008 if they are not). This may reflect the increased risk of inadvertent IMC entry at night - a possibility strengthened by the similar pattern for flight in rain (p=0.541 for day, p=0.0643 for night). The increased severity associated with snow appeared to be independent of day or night conditions.

Outside Visual References.

No significant relationship DURING INSTRUMENT FLYING could be found between the severity of disorientation episodes and outside visual references (as graded 'good', 'acceptable' or 'bad' by respondents).

For VISUAL FLYING, there was a trend for increasing severity with worsening outside visual references but this did not reach statistical significance for the 'worst ever' group. For the 'worst episode in 4 months' group it was highly significant at the p=0.001 level. For both combined, the significance was heightened (p=0.00089). Yet again, there were strong day /night effects (p=0.415 by day, n=74, and p=0.0071 by night, n=91). No differences were detectable between the effects of different grades of outside visual references on NVG and non-NVG flight.

Sortie Types.

Using General Handling/Familiarisation sorties as a standard, no significant differences in the severity disorientation episodes were detected for the following sortie types or conditions: Military Exercises, Observation and Reconnaissance, Armed Action, Casevac or Transit Flying. (These figures are for the combined 'worst ever' and 'worst in 4 months' data.)

Troop Insertions showed a statistically significant increase in 'severe' episodes (p=0.016). Too few of these sorties were reported for further statistically significant analysis (n=23), but no changes in the pattern were apparent when breaking the sorties down by day/night/nvg. There are a number of confounding factors present in this result - for example, most troop insertions were in Lynx, Scout or A109 aircraft and only 2 involved the Gazelle. Nine were in Northern Ireland and 5 in the Gulf.

Instrument Flying sorties showed NO statistically significant difference to the 'standard' sorties although the trend was for a relative over-representation in 'minor' episodes (p=0.084). When cases of the 'leans' are excluded the figures become insignificant (p=0.433). No differences were detectable between Instrument Flying in simulated or actual conditions (p=0.998 with the 'leans' included and p=0.6441 when they are not). Similarly, there were no significant differences or apparent trends when Instrument Flying in 'actual' conditions was analyzed according to whether it was for training or non-training purposes.

Mountain Flying Sorties (n=17) showed NO trends compared with the 'standard' sorties (p=0.407).

These results are at odds with the subjective views of respondents who were asked to grade sortie types on their likelihood to provoke disorientation using a scale of 1-7 where one was 'much less likely to induce disorientation than other types', 4 was average and 7 was 'much more likely to induce disorientation'. Two distinct groups were generated. Those that were NOT seen as provocative had average marks of between 2 and 3 and comprised; Military Exercises, Observation and Reconnaissance, Armed Action, Casevac, Familiarisation Flying and General Handling. The PROVOCATIVE group all had average marks of between 5 and 6 and comprised; Mountain Flying, Simulated Instrument Flying and Actual Instrument Flying. A Friedman analysis ranked them in that order (the last being most provocative) (Friedman p=0.0000).

Aircraft Type.

Respondents were also asked to grade Aircraft Type in a similar manner to sortie type. (They were specifically asked to consider aircraft type and sortie type independently and to not allow the effects of one to influence their views on the other.) Helicopters in common use were ranked by a Friedman analysis as; Lynx, Scout, Lynx Simulator and Gazelle (with the last being most provocative) (p=0.0004). Mean scores from respondents were 3.30, 4.01, 4.14, and 4.30 respectively. There were too few assessments of Fixed Wing aircraft for useful analysis (n=12).

An analysis of these 3 main helicopter types (Scout, Lynx and Gazelle) against the severity of 'worst ever' episodes revealed no statistically significant differences, although there was a trend for Scout to be over-represented in 'severe' episodes. For the 'worst in 4 months' figures the trend was for over-representation of Lynx in 'severe' episodes. There are confounding factors at play such as variations in flying experience, solo flying and sortie types.

Attempts to compare Lynx against Gazelle under specific conditions revealed no significant differences in the severity of the 'worst in 4 months' episode for ordinary night flying (p=0.50), day flying (p=0.33), IF (p=0.328) or outside visual references (p=0.246). During NVG use there was a trend for Lynx to be associated with episodes of increased severity (p=0.095). This is interesting when put beside the likelihood of 2 crew members being disorientated at the same time (see 'Other Members of the Crew Disorientated' below). Also interesting are the results of the analysis of flying manoeuvres, when broken down by aircraft type (see 'Flying Manoeuvres' below).

Flying Manoeuvres.

A mostly unsuccessful attempt was made to assess the influence of various flight paths or manoeuvres (straight and level, turning, climbing/descending or accelerating/decelerating) by comparing them against each other DURING INSTRUMENT FLIGHT. The combined 'worst ever' and 'worst in 4 months' data were analyzed.

Using straight and level flight as a 'standard', no trends in the severity of episodes could be discovered for any manoeuvres, except for an over-representation of 'significant' and 'severe' episodes during acceleration or deceleration (p=0.069). The trend was made marginally stronger when considering Gazelle aircraft alone (p=0.051) despite the reduction in numbers (n=34 from n=59). Using Gazelle aircraft alone, an increase in severity for episodes involving climbing or descending also became apparent (p=0.054 as opposed to p=0.232 for all aircraft types combined). Manoeuvres involving acceleration or deceleration also frequently involved climbing or descending (82% of Gazelle accelerations/decelerations, 85% of all aircraft accelerations/decelerations) - it is therefore difficult to analyze these manoeuvres by themselves. If episodes of the 'leans' are excluded from the analysis, no significant relationship could be demonstrated between severity of episode and any manoeuvre (irrespective of aircraft type) - but this may partly reflect the reduced numbers in the equations.

A similar picture was produced when manoeuvres were analyzed by their presence or absence during an episode - rather than against a 'standard'. Table 3 gives the results. Both climbing (or descending) and accelerating (or decelerating) were associated with increased severity of episodes - until cases of the 'leans' were removed, following which no significant relationships could be demonstrated. For climbing or descending the significance level remained about the same when the Gazelle was considered by itself (p=0.0484) despite the drop in numbers. This was not so for acceleration/deceleration, where the 'all aircraft types' data was more significant (p=0.00718) than for the Gazelle alone (p=0.10). There was no significant relationship between the incidence of the 'leans' and the Gazelle when compared to other aircraft (p=0.935).

It was felt that there were too many confounding factors present for any sensible analysis of flight manoeuvres occurring OUTSIDE Instrument Flight. Differences were present, however, with indications of type specific influences. (For example, episodes involving acceleration/deceleration in the Gazelle were associated with increased severity (p=0.00129). No such association existed for Lynx (p=0.858)). These results should be treated with caution both because of the confounding factors mentioned before (which would include variations in pilot experience, sortie type and location) and because of differences in the numbers of each aircraft type considered.

Crew Position.

'Worst ever' episodes were more likely to be 'severe' and less likely to be 'significant' for those who were the Aircraft Commander at the time of the episode when compared to those who were the Co-pilot (p=0.0003). This pattern is not the result of Instrument Flying Training (during which any pilot might become a Co-pilot 'under the hood') since it was unaffected by stripping out episodes of the 'leans' (p=0.03) or when considering VMC flying only (p=0.07).

This difference between aircraft commanders/co-pilots was not repeated in the 'worst episode in 4 months' data despite the very similar numbers (p=0.48). The combined groups showed a pattern similar to that of the 'worst ever' group alone.

Numbers in Crew.

For the 'worst ever' group, the crew composition had a significant effect on the severity of episodes. 'Severe' episodes were more likely to have occurred to solo aircrew rather than 2-pilot or pilot/aircrewman combinations (p=0.007). Similarly, Aircraft Commanders flying with Aircrewmen had more 'significant' and 'severe' episodes than when they flew with Co-pilots (p=0.027).

The 'worst in 4 months' group showed no statistically significant trends (but the number of solo aircrew was only 16). When the 2 groups were combined the significance levels rose. (For example, the increase in severity when an Aircraft Commander was flying with an Aircrewman as opposed to a Co-pilot reached p=0.00029. The difference persisted both VMC and IMC; p=0.005 and p=0.06 respectively.)

Other Members of the Crew Disorientated.

In 41 (18%) of 'worst ever' episodes both front seat crewmembers were disorientated (in 22 the Aircraft Commander reported that his Co-pilot or Aircrewman had also been disorientated, in 19 it was vice versa). One Ac Comd reported that a full crew in another aircraft had also been disorientated! Episodes involving disorientation of both crew members were more likely to be graded 'severe' and less likely to be graded 'significant' (p=0.0166). Comparison within this group showed differences in severity dependant on the other crewmember's position. If the other crewmember was the Commander the episode was more likely to be 'severe' while if he was a Co-pilot it was more likely to be 'significant' (p=0.035).

The picture was similar for the 'worst in 4 months' group. In seven of these episodes (4%) a Co-pilot stated that his Aircraft Commander had also been disorientated, while the reverse was true in 18 (10%) of episodes. Again, the episode was much more likely to be 'significant' or 'severe' if the other crewmember was disorientated (p=0.00008).

When the data from the 'worst ever' and 'worst in 4 months' were combined, the other crewmember was disorientated in 24% of episodes involving non-NVG flight at night. For NVG flying the figure was even higher at 44%. This association between Night Flying and the likelihood of another crewmember being disorientated at night was statistically very strong (p=0.00001) and was true for both non-NVG flight (p=0.0063) and NVG flight (p=0.00000). Furthermore, NVG flight was significantly more likely to be associated with disorientation in another crewmember than non-NVG night flight (p=0.0379).

Lynx aircraft showed a greater tendency for more than one crewmember to be disorientated than did the Gazelle (p=0.073). Further analysis showed no difference between these aircraft for Day Flying (p=0.95) or for Instrument Flying (p=0.456). There were differences for Night Flying, however, (p=0.00726). This type specific difference appeared to be directly related to NVG flight (p=0.989 for non-NVG flight, p=0.0929 for NVG flight) and it was not easily explained by variations in aircraft types used in the Gulf or Northern Ireland (p=0.638) or by overall NVG flying hours (p=0.17).

Aircrew Qualifications.

An analysis of the data for the 'worst ever' group revealed no statistically significant differences in severity between respondents who were Aircraft Commanders and those who were QHIs at the time of the episode (p=0.42). Episodes were, however, more likely to be 'severe' and less likely to be 'significant' for Aircraft Commanders when compared to Co-pilots (p=0.002).

Interestingly, no statistically significant relationship between aircrew qualification and the severity of the 'worst in 4 months' episode was discernible, although the trend was for increasing qualification (from Co-pilot through Aircraft Commander to QHI) to be associated with reducing severity (p=0.29). This trend might become more significant if allowance was made for varied flying rates, since QHIs flew a significantly more number of hours than other aircrew (p=0.009).

Also of interest was the lack of a statistically significant relationship between Instrument Rating (graded Amber, White, Green or Master Green) and the severity of the 'worst in 4 months' episode (p=0.43). Furthermore, no statistically significant association could be found between severity and a lapsed Instrument Rating (n=14 for those who had flown during the period), although the trend was for a lapsed rating to be associated with increasing severity (p=0.11).

Equipment.

A number of equipment influences were reported, ranging from the Lynx Armoured seat (1 report) through clothing and survival equipments to Infra Red sensors and Night Vision Goggles. In general, too few reports were generated for each for satisfactory analysis - although Night Vision Goggles were associated with an increase in severity of disorientation episodes (p=0.00003). The important findings for Night Vision Goggles, however, might be considered to be the high incidence of disorientation, the lack of difference when compared to ordinary night flying (reported earlier under 'Light Conditions') and the differences noted above under 'Other Members of the Crew Disorientated'.

State of Health and Mind.

For the 'worst ever' group 196 respondents reported that they had been healthy at the time of the incident, compared to 4 who had had minor problems (2 minor illnesses, 1 backache and 1 hangover). The figures for the 'worst in 4 months' group were similar (160 healthy, 3 minor illnesses and 1 hangover).

For the 'worst ever' group 129 had been alert, 66 tired and 8 very tired. Seven had been bored. No statistically significant relationship could be shown between the severity of the episode and being tired or very tired (p=0.283). The figures for the 'worst in 4 months' group were; alert 117, tired 44, very tired 6, and tired and bored 3. In this group, being tired or very tired was associated with increased likelihood of a 'severe' episode (p=0.022).

When the data were combined, being tired or very tired was associated with an INCREASED likelihood of a 'significant' or a 'severe' episode (p=0.0164) while being bored was associated with REDUCED severity (p=0.045).

For the 'worst ever' group, 122 had been undistracted at the time of the episode. 46 had been distracted by flying matters, 14 by non-flying matters and 1 by both. There was no significant association with severity of episode. For the 'worst in 4 months' group the figures were; undistracted 112, distracted by flying matters 29, distracted by non-flying matters 16 and distracted by both 3. There was a significant association between being distracted (for whatever cause) and the likelihood of a 'severe' episode (p=0.028). This relationship disappeared, however, when both groups of data were combined (p=0.25).

When comparing Lynx and Gazelle aircrew, the latter were more likely to have been distracted by flying matters but at a 'trend' level only (p=0.09). If solo aircrew are removed from the analysis the probability level drops to 0.14.

No significant differences in severity of episodes could be discovered for those who had taken alcohol in the previous 24 hours and those that hadn't. 58% of the 'worst ever' group and 79% of the 'worst in 4 months' group specifically stated that they had not taken alcohol in the 24 hours previous to the incident. Only 10% of the former and 6% of the latter stated that they had taken alcohol, the rest were unable to remember.

Perceptual Factors.

The description of each episode was analyzed to yield information about which senses had been involved and whether the problem had been due to an illusion or due to a failure to perceive what was happening (many were mixed, of course). Tables 4 and 5 give figures for the breakdown of the 'worst ever' and 'worst in 4 months' groups respectively.

When broken down by senses no statistically significant association could be derived between severity and whether the problem had been an illusion or a failure to perceive. For all senses amalgamated, however, a failure to perceive was significantly associated with an increased risk of a 'severe' episode (p=0.002 for the 'worst ever' group and p=0.00000 for the 'worst in 4 months' group). Episodes of the 'leans' were classed as illusions and when these were stripped out, the pattern was less evident (p=0.15 for the 'worst ever' group and p=0.003 for the 'worst in 4 months' group).

In the 'worst ever' group, 14 episodes involved a missed descent or ascent (5 were associated with a missed turn as well) and 12 involved unintentional sideways or rearwards flight. For the 'worst in 4 months' group the figures were; missed ascent or descent 7 (3 with a missed turn) and unintentional sideways or rearwards flight 5. (In neither group were there any missed turns by themselves.) When both groups of data were combined there was a strongly significant increase in the severity of disorientation for those respondents who were victims of unintentional flight manoeuvres when compared to those that were not (p=0.00000). This remained true when cases of the 'leans' were stripped out (p=0.037).

Operational Circumstances.

Table 6 gives a breakdown of the circumstances for the 'worst ever' and 'worst in 4 month' episodes, as derived from respondents' descriptions.

A series of Chi-Square tests on the data from the 2 groups combined showed that there were significant differences in severity, with routine IMC flight being associated with relatively few 'severe' episodes while inadvertent entry into IMC, whiteout (or similar) and poor visual cues in acceptable visibility were all associated with increased severity (p=0.0000). Chi-Square tests on the latter group showed that poor visual cues had the least relative impact while inadvertent entry into IMC entry with VMC recovery had the most (p=0.0023). In between - and at much the same severity as each other - were Inadvertent IMC with IF recovery and whiteout/brownout. A comparison of recovery to VMC flight against recovery to Instrument Flight following inadvertent entry to IMC showed that the relatively increased severity associated with the former was marginally significant (p=0.066).

Effects on Aircraft Control.

Table 7 is derived from respondents' descriptions and details the apparent effects of the different episodes on aircraft control.

In only 30% of 'worst ever' and 57% of 'worst in 4 months' episodes had the respondent been able to work through his disorientation without effects on aircraft control. This is not to say that control effects were always serious. However, flight safety was jeopardised by definition in 24% and 6% of each group respectively (since those are the rates for 'severe' incidents). Many stories were horrific - for example in one episode (classed by the respondent as 'significant' rather than 'severe'(!)) a Lynx did 10 pirouettes while landing in formation with 6 others.

Geographical Location.

Table 8 breaks down the disorientation episodes by geographical location. It should be emphasised that these locations are only those deducible from the descriptions - it was a failing of the questionnaire that it did not specifically ask for the location. Using Germany, the Low Countries and UK (less Middle Wallop) as a 'standard', no statistical difference in severity of episode could be discovered for Northern Ireland or Norway in either group. There was, however, a highly significant increase in the severity of episodes being reported from the Gulf (p=0.004).

Break Off.

Tables 9 gives the numbers of respondents who reported 'Break Off' phenomenon (using the same definitions of severity) 'at some point during their career' and 'in the 4 months previous to the survey'. Although the survey was not designed to review factors that might be involved in 'Break Off' phenomenon, a brief analysis of those respondents who reported at least one episode in the previous 4 months showed no apparent relationship with total experience, aircrew qualification, unit or aircraft type. There was a trend for aircrew with an amber or white instrument rating to be more likely to suffer than those with a green or master green rating (p=0.056). This might partially reflect other factors such as confidence. There were too few sufferers with lapsed ratings for a meaningful analysis.

Disorientation Training Sorties.

Respondents were asked to rate the value of the disorientation training sortie by ticking one of 5 boxes. Table 10 records the results - which were very much in favour.

Surprisingly, there was no significant relationship between flying experience and the likelihood to consider the sortie 'neutral' or 'harmful'. It had been expected that the older and more experienced aircrew would be less likely to be enthusiastic.

No significant relationship could be discovered between views on the sortie and currency on different aircraft types, severity of the worst episode ever suffered, aircrew qualification or instrument rating.

Aircrew Comments.

Aircrew were asked to comment on any matter that they considered relevant. These are not reported here - but about 480 separate comments were received. Stability Augmentation Systems, full Navigational Aid Suites and better instrument ergonomics were seen as beneficial measures. Equally, the increasing pressure from non-flying 'soldierlike' duties was seen as an emerging threat to professional - and safe - military flying.

DISCUSSION.

Disorientation is so multifactorial that a survey such as this is bound to flag up more questions than it answers - particularly since the results are based on aircrew perceptions and are thus heavily subjective. Nonetheless, interesting information was produced on the incidence and genesis of disorientation for both the 'snapshot' 4 month period and for the longer 'complete career' timescale.

Incidence.

The findings that 90% of aircrew had been disorientated at some time in their career and that 24% had suffered at least one episode in which flight safety had been jeopardised are broadly similar to the results from other surveys - although variations in definitions make detailed comparisons difficult (4,5,6,8).

More interesting is the 'snapshot' incidence over the 4 months previous to the survey. Here it is difficult to quantify the effect of the Gulf War since the knock on effects influenced flying rates and other factors elsewhere. There is no doubt, however, that aircrew found flying over the desert particularly disorientating.

Including the Gulf figures, therefore, gives a 'maximum' incidence of disorientation in the 4 months previous to the survey, revealing that 6% of Army aircrew suffered 'severe' episodes (i.e. episodes in which flight safety was put at risk). Excluding the figures from the Gulf should produce a 'minimum' rate since the knock on effects in other theatres were in general more likely to reduce the incidence of disorientation (reduced flying rates etc.) This 'minimum' rate is 4% and the true 'peacetime' rate might therefore be slightly higher at about 5%. This is disturbingly high, although it should be noted that seasonal factors may well play a part in the incidence of disorientation and this rate is not 'annualized'.

Also disturbing is the 'wartime' rate thrown up by the Gulf. The actual flying rate in the Gulf was significantly LESS than in other theatres (Mean 58, std dev 45 compared with mean 91 std dev 51, T-test p=0.005) and this highlights the significant increase in 'severe' episodes suffered by Gulf aircrew when compared to aircrew in UK or Germany (p=0.004). This high rate from the Gulf reflects the difficulties of the terrain, climate and operational scenario. Future wars may have different sets of circumstances, but commanders should be aware that disorientation is not just a peacetime problem and may affect wartime attrition rates. This point has been raised before (7).

The finding that loss of flying control is so frequent a concomitant of disorientation (43% of respondents had had some loss of control in the previous 4 months) also points to the fact that although disorientation has been studied for many years there are insufficient measures are in place to protect aircrew from its effects.

Relevant Factors.

Aircrew Factors.

The multiplicity of factors involved in disorientation showed up in many results - for example in the peculiar finding that sufferers of 'significant' episodes had statistically fewer flying hours than those who suffered 'minor' or 'severe' episodes. Buried in amongst a number of confounding factors (such as variations in aircraft types) may be 2 conflicting trends associated with greater flying hours - an increased chance of suffering a particularly bad experience and an increased likelihood of being sanguine about less severe episodes. Only further study could tease out the relevant factors.

The association between both crew position and crew numbers to the perceived severity of episodes was expected - since either would affect the extent to which flight safety was threatened. An expected association that did not materialise, however, was that between Instrument Rating and severity of disorientation. Since the classical 'cure' for disorientation is to get onto instruments, a higher qualification might be expected to ease the severity of the episode but this did not appear to be the case (at least for the data from the 4 months previous to the survey -data for the other group was not sought). Indeed, the only protection given by a higher instrument qualification seemed to be in the area of 'break off' - and here it was marginal only (and liable to the influence of other confounding factors such as individual confidence). This lack of association between Instrument Rating and severity of disorientation is in alignment with the finding of Vyrnwy-Jones that aircrew in US Army Orientation Error accidents had much the same overall flying and Instrument Flying experience as those of a control group whose accidents were due to technical failure (7).

Also expected was the association between severity of episode and whether or not the other crew member was disorientated. The high frequency of both members being affected was a surprise although it has been commented on in other surveys (5,7). The levels were particularly serious for Night and NVG flying - the fact that ALMOST HALF (44%) of NVG episodes involved disorientation of both crew must be of concern to operators and should lead to efforts to improve cockpits and operational procedures.

For such a subjective and 'perceptual' event as disorientation, the effects of being tired were not a surprise. Indeed, it might be considered that the association between tiredness and the perceived severity of episodes was not as strong as it could have been. When both sets of data were combined, and 'severe' and 'significant' episodes were amalgamated, the significance level reached p=0.0164 - which is less than for many other factors analyzed. This most certainly does NOT mean that these effects should be ignored - they will become more and more important as operating pressures increase as a result of financial constraints and the introduction of new equipments.

Similarly, the finding that distraction during flight was associated with increased numbers of 'severe' episodes (at least for the 'worst episode in the past 4 months' group) is unsurprising but worthy of attention.

That boredom was associated with the opposite trend of REDUCED levels of severity was interesting and might reflect the possibility that one is only likely to be bored if there is plenty of flight safety margin in hand. It proves the point that if operators make aircraft easy to fly and boring they are likely to be safe!

Crew health proved satisfactorily irrelevant in that very few respondents were anything less than fully healthy at the time of their episodes. Similarly, the lack of association with alcohol is a testament to the awareness of modern aircrew.

The attempt to break down narrative descriptions to yield the prime body sense involved should be treated with caution because it was highly subjective. Helicopter flying is a very visual occupation and so it was no great surprise that 40% of the episodes that could be easily classed as visual or vestibular appeared to be visual in origin. Neither was it a surprise that poor external visual references were associated with increased severity of episodes, although it was interesting that type 1 errors (when aircrew are unaware of the problem) accounted for about 50%

of episodes involving vision. As expected, type 1 episodes (irrespective of sense involved) were marked by aircrew as being more serious in terms of flight safety.

Operational Factors.

For Instrument Flying the picture produced was one of much increased INCIDENCE but of only marginally increased SEVERITY of episodes (once the 'leans' had been stripped out). Indeed the severity of episodes occurring during daytime IF appeared very similar to that during day Visual Flying episodes. It was only at night that IF was associated with an apparent increase in severity over Visual Flying - and this may reflect the increased chances of inadvertent IMC entry at night. This is not to say that disorientation during daytime IF is benign (10% of cases were 'severe' and 34% 'significant'). Operators should remember that not only is anything that jeopardises flight safety a matter for concern but that it will affect efficiency at carrying out the sortie task. In other words, measures to reduce disorientation would have benefits in the area of efficiency as well as the area of pure flight safety. Efficiency might be particularly 'geared up' during operational scenarios involving high workload an other stresses.

Inadvertent IMC proved to be associated with a greater severity of episodes than any other isolated operational circumstance including whiteout/sandout/dustout. This may reflect the fact that the loss of visual cues is particularly difficult to cope with because it is unforeseen. Disorientation appeared to be a greater threat to flight safety when inadvertent IMC was followed by recovery to Visual Flight rather than when it led to Instrument Flight. This could either be a function of circumstances preventing Instrument Recovery (e.g. icing risks) or it could reflect the safety value of a climb to altitude and a call for radar assistance.

The fact that Night Flying (both non-NVG and NVG) was associated with a greater incidence and a greater severity of episodes was also expected (previous surveys have found the reduced cues of night time provocative (4)). It had been expected that NVG flight - with the associated reduced field of view and reduced visual acuity - might be more provocative than non-NVG night flight but this did not prove to be the case (presumably because NVGs do at least allow you to see something even if the image is unnatural and of comparatively poor quality). It is difficult to explain the increased propensity for Lynx (when compared to Gazelle) to be associated with BOTH crewmembers being disorientated during Night Flying. The effect appears to be related to NVG use and hypotheses that it might reflect different geographical locations or varying NVG flying rates appear unfounded. It may be a true aircraft type difference - since the Lynx has a less open cockpit than the Gazelle - but caution should be used in interpreting the result because Lynx aircrew do differ from Gazelle aircrew in experience and the aircraft types do have different roles. In particular Troop Insertion (which was found to be a particularly disorientating sortie type) is likely to be a Lynx role which might be undertaken on NVGs. (The reverse might equally be true, of course, and Troop Insertion might appear more disorientating simply because of its association with Lynx NVG operations).

It was interesting that no statistically significant increased severity of episodes could be detected for Mountain Flying sorties. The subjective feelings of aircrew were strongly that Mountain Flying rated with Instrument Flying (both Simulated and Actual) as a source of disorientation. It is possible that - just as Instrument Flying is associated with an increase in incidence but not of overall severity - so Mountain Flying might lead to more episodes which are not in themselves particularly severe. Alternatively, the number of mountain flying episodes (n=17) may have been insufficient to detect any associated variations in severity.

Associated closely with differences in sortie type is the question of geographical location. The questionnaire did not specifically ask for information on location but so many narratives included this information that some comparisons were possible. It was expected that Norway, Northern Ireland and the Gulf would produce the most severe episodes of disorientation but in the event a significant relationship could only be shown for the last. This probably reflects operational, terrain and climatic factors.

Aircraft and Flight Path Factors.

The propensity of Lynx to be associated with more than one crewmember being disorientated simultaneously has been mentioned above. This - and the marginally increased severity of Lynx NVG episodes in general (when compared to Gazelle) - was unexpected. The Army version of the Gazelle has no Stability Augmentation System and it was thought that any differences in aircraft type would be likely to point to the Gazelle as being more disorientating. This latter view was supported by the ratings given by the aircrew which classed the Gazelle as significantly 'worse' than the Lynx. It was also supported by the tendency for manoeuvres in the Gazelle to be associated with increase in severity (both during Instrument Flight and during Visual Flight) whereas no such association appeared to exist for the Lynx. This might be a spurious result and should be treated with caution - confounding factors such as differing levels of aircrew experience make it difficult to interpret. Nonetheless, these findings support intuitive expectations as well as aircrew opinion.

Aircraft specific factors provide an area worthy of future research.

Break Off Phenomenon.

The numbers of rotary wing aircrew reporting 'Break Off' confirmed previous reports that it does happen in helicopter aircrew (1,3,4,8). A total of 9% of Rotary Wing respondents had suffered a 'severe' episode (the same definitions being applied as for other episodes of disorientation). One reported an 'out of cockpit' experience with the comment that "...there is nothing like seeing your aircraft start dropping out of control to get you back in the cockpit again...". The finding in this survey of an apparent relationship with Instrument Rating is interesting but may be a product of personal qualities such as 'confidence' -after all, 'Break Off' is a psychological more than a physiological event. More research is needed into how this interesting phenomenon affects the helicopter community.

Disorientation Training.

The whole hearted support of the aircrew for the airborne disorientation training sortie was reassuring. The sortie is effective in teaching aircrew that their abilities in the air are limited but it unfortunately concentrates on the 'non-visual' element of disorientation (in that aircrew are asked to sense various manoeuvres with their eyes effectively blindfolded). It is difficult to introduce 'visual' illusions but consideration should be given to developing an appropriate sortie.

Final Comment.

This survey has shown that disorientation continues to be a problem in UK Army helicopter operations. Continued pressure is necessary to ensure that:

- Research and Development of improved Instrument Displays and other systems to present information continues.

- Operators are made aware of the effects of equipment such as NVGs.

- Operators are made aware of the effects of Human Factors such as state of mind.

- Aircraft are properly equipped to minimise both the risks of inducing disorientation and its effects (measures should include full stability systems and appropriate Navigation Systems)

It may be expensive - but aircraft and aircrew losses are even more so.

ACKNOWLEDGEMENT.

Sincere admiration and thanks are due to all the aircrew who responded to the questionnaire. Not only did they take the time and trouble to fill in the 10 sides accurately but they also gave deep consideration to the problem of disorientation and how to prevent it. As always, their sense of humour made it a joy to read their responses.

Severity of Worst Ever Episode.	Mean Flying Hours of Respondent AT THE TIME OF THE EPISODE	Standard Deviation	Comparison with the middle ('Significant') group. (T-test)
'Minor'	1090	1400	Different p=0.031
'Significant'	723	681	
'Severe'	1114	1013	Different p=0.006

TABLE 1. Grade of Worst Ever episode suffered against Flying Experience AT THE TIME OF THE EPISODE (excluding respondents whose worst episode was in the 4 months previous to the survey).

Severity of Worst Episode in the previous 4 months.	Mean Flying Hours of Respondent AT THE TIME OF THE EPISODE	Standard Deviation	Comparison with the first ('Minor') group. (T-test)
'Minor'	1599	1417	
'Significant'	1019	890	p=0.02
'Severe'	986	688	p=0.004

TABLE 2. Grade of the Worst Episode in the previous 4 months against Flying Experience AT THE TIME OF THE EPISODE.

Flying Manoeuvre	Association between manoeuvre and severity of episodes. (INCLUDING cases of 'leans').	Association between manoeuvre and severity of episodes. (EXCLUDING cases of 'leans').
Straight and Level	Nil. (p=0.497)	Nil. (p=0.667)
Turning	Reduced severity (p=0.00506)	Nil. (p=0.230)
Climb/descent	Increased severity. (p=0.0454)	Nil. (p=0.640)
Acceleration/ deceleration.	Increased severity. (p=0.00718)	Nil. (p=0.855)

TABLE 3. The severity of episodes for different flying manoeuvres when compared to episodes not involving those manoeuvres. (Data from 'worst ever' and 'worst in 4 months' groups combined, Instrument Flying only).

Body Sense	Failure to Perceive	Illusion
Vision	19	33
Vestibular Organs	1 (excl 'leans')	73 (incl 'leans')
Mixed	29	38
Others	'Break Off' 'Central Processing Failure'	- nil. - 9.

TABLE 4. Body Sense and comparative rates for 'Failure to Perceive' or 'Illusion' (judged on the most important element in the history). 'Worst Ever' group.

Body Sense	Failure to Perceive	Illusion
Vision	15	30
Vestibular Organs	1 (excl 'leans')	70 (incl 'leans')
Mixed	15	22
Others	'Break Off' 'Central Processing Failure'	- 2. - 2.

TABLE 5. Body Sense and comparative rates for 'Failure to Perceive' or 'Illusion' (judged on the most important element in the history). 'Worst in 4 months' group.

	'Worst ever' group	'worst in 4 months' group
Routine IMC flight	96 (45%) (incl 64 'leans')	86 (50%) (incl 76 'leans')
'Whiteout' or similar loss of visibility	9 (4%)	8 (5%)
Inadvertent IMC	20 IF recovery (9%)	5 IF recovery(3%)
	11 VMC recovery(6%)	5 VMC recovery(3%)
Visibility OK but visual cues absent/misleading	57 (27%)	50 (29%)
Others	16 (7%)	13 (8%)

TABLE 6. Circumstances of 'worst ever' and 'worst in 4 months' episodes as derived from respondents' descriptions.

	'Worst Ever' group	'Worst in 4 months' group
Able to work through it	54 (30%)	77 (57%)
Temporary Loss of flying control	46 (26%)	22 (16%)
Handed over control	26 (15%)	7 (5%)
Not on controls (includes a number who took control to regain orientation)	16 (9%)	11 (8%)
Unable to recover to normal flight (accidents, heavy landings etc.)	11 (6%)	4 (3%)
Others	25 (13%)	15 (11%)

TABLE 7. The effects of disorientation on aircraft control.

	'Worst Ever' group	'Worst in 4 months' group
Northern Ireland	27 (12%)	19 (10%)
Norway	13 (6%)	3 (2%)
Germany/Low Countries/Channel	23 (10%)	6 (3%)
UK (less Middle Wallop)	13 (6%)	10 (5%)
Middle Wallop	44 (19%)	18 (10%)
Far East/Africa /Mediterranean	3 (1%)	nil
Falklands	2 (1%)	nil
BATUS	2 (1%)	nil
Gulf/Iraq	5 (2%)	21 (11%)
Others/undefined	95 (42%)	109 (59%)

TABLE 8. Geographical location of episodes.

	At least one episode during whole career	During the 4 months previous to survey
'Minor'	54 (16%)	10 (3%)
'Significant'	23 (7%)	5 (1.4%)
'Severe'	9 (3%)	1 (0.3%)

TABLE 9. Numbers of Rotary Wing aircrew reporting at least one episode of 'Break Off' phenomenon 'during the respondent's whole career' and 'during the 4 months previous to the survey'.

	Aircrew	Views		
Beneficial	<--->	Neutral	<--->	Harmful
180	75	63	4	nil

TABLE 10. Aircrew views on the Disorientation Training Sortie (numbers of respondents marking each box). A number put arrows to indicate that their opinion was off the scale to the left.

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Illusions otolithiques au décollage et informations visuelles: Réflexions à propos d'un cas d'accident aérien

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Résumé

Les illusions otolithiques au décollage (take-off illusions) sont connues de longue date comme cause d'accidents aériens. Elles ont pour origine l'accélération + Jx de l'appareil qui, en se composant avec le vecteur gravité, produit une stimulation otolithique générant une sensation de cabré excessif (illusion somatogravique). Ce type d'illusion se manifeste essentiellement lorsque les références visuelles sont insuffisantes (décollage de nuit, environnement brumeux). Un accident aérien ayant conduit à la perte d'un avion de combat moderne est rapporté. Les circonstances et les différents paramètres de vol (accélérations Jx et Jz, vitesse, trajectoire et altitude, actions pilote, ...) sont analysés. A partir de ces données, la stimulation otolithique résultante subie par le pilote au cours du vol a été reconstituée. L'évolution de cette stimulation permet d'expliquer parfaitement les actions effectuées par le pilote, faisant de cet accident un exemple typique d'illusion au décollage. L'analyse de cet accident aérien montre qu'à aucun moment le pilote ne semble avoir utilisé les informations visuelles d'attitude présentées dans le viseur tête haute de l'appareil. A partir de ces éléments, une réflexion est menée sur les informations visuelles d'orientation spatiale présentées dans les viseurs. Elle conduit à envisager les différentes solutions susceptibles de réduire les risques de désorientation. L'introduction de systèmes de visualisation liés à la tête pose un certain nombre de problèmes nouveaux dans ce domaine, mais ouvre également des perspectives intéressantes.

1. INTRODUCTION

Le rôle joué par la désorientation spatiale à l'origine des accidents aériens a depuis longtemps clairement été établi. La plupart des forces aériennes ont maintenant entrepris des programmes d'entraînement destinés à diminuer l'incidence de ces accidents. En dépit des progrès indéniables qui ont résulté de l'amélioration des procédures d'entraînement et des efforts entrepris dans le domaine de la présentation des informations de pilotage, la menace de désorientation spatiale demeure toujours un risque préoccupant. Dans une étude portant sur les cas d'incapacitation en vol survenus ente 1970 et 1980 dans l'US Air force Rayman et Mc Naughton (14) relèvent 25 cas où ce facteur a été formellement mis en cause. Le décollage de nuit ou dans les nuages constituait le contexte de survenue dans 8 cas. L'actualité de tels accidents est également mentionnée par Gillingham et Wolfe, reliée aux illusions somatograviques, dans une revue remarquablement exhaustive des problèmes d'orientation spatiale en vol (7), accompagnée d'une description qui souligne leurs caractéristiques très stéréotypées.

En fait, les illusions au décollage ont déjà fait l'objet de nombreuses descriptions, ceci dès la fin du second conflit mondial, en particulier par Collar (1946), ainsi que le rapportent Buley et Spelina (1) dans leur revue des facteurs physiologiques et psychologiques impliqués dans les accidents au décollage par nuit noire (" Dark night takeoff accident"). Ces auteurs soulignaient alors le problème des informations visuelles d'attitude et l'inefficacité de la simulation de vol pour la prise en compte de ce phénomène par l'entraînement. Il faut également citer les travaux de M. Cohen sur l'effet des catapultages à partir de porte-avions (3, 4, 5) qui ont complété ces descriptions en s'appuyant sur une série d'études expérimentales en centrifugeuse, apportant ainsi des éléments quantitatifs sur l'intensité et la dynamique de ces illusions, ainsi que sur les interactions visuo-vestibulaires mises en jeu.

Le mécanisme de base commun à l'origine des illusions somatograviques repose sur l'ambiguïté fondamentale qui existe au niveau de la transduction mécano-nerveuse otolithique. En effet, par principe, les capteurs otolithiques ne peuvent faire à eux seuls la différence entre l'effet de la composition d'une accélération linéaire dans le plan de la macule avec le vecteur gravitaire et le changement d'orientation de ce même vecteur du fait d'une inclinaison de la tête (fig. 1). L'orientation de la force agissant sur la macule est identique et génère un effet mécanique pratiquement similaire dans les deux cas. Cette ambiguïté est normalement levée par l'apport d'informations sensorielles complémentaires, essentiellement d'origine visuelle ou canalaire qui, lorsqu'elles font défaut ou sont volontairement faussées (simulation de vol), laissent la place à une perception erronée de la situation.

Dans le cas du décollage, ceci conduit à une perception d'attitude excessivement cabrée de l'appareil (par extension du schéma corporel) et, en l'absence d'informations cognitives pertinentes, à des corrections de trajectoire inappropriées. L'accident aérien rapporté ici est à ce titre particulièrement démonstratif.

2. ANALYSE DE L'ACCIDENT

Après avoir décrit le contexte et le déroulement du vol, les différents évènements feront l'objet d'une analyse neurosensorielle prenant en compte les stimulations otolithiques subies par le pilote.

2.1. Contexte de l'accident

Les faits: 36 secondes après le lâcher des freins un avion de combat moderne s'écrase au bout de la piste de décollage. Après le décollage, l'ascension culmine à environ 450 pieds AGL (au dessus du niveau du sol). Le pilote est tué et l'appareil totalement détruit.

Conditions météorologiques: Une couche nuageuse peu épaisse, elle se termine à environ 1500 pieds, mais dense recouvre le terrain. La base des nuages se situe à environ 160 pieds. Sous la couche, la visibilité est de 1700 m. le vent est calme, le QNH à 1033 hPa et la température est de 7 °C. Ces données définissent une condition opérationnelle "Rouge Spécial".

Expérience du pilote: Il s'agit d'un pilote considéré comme bon, dont le nombre d'heures de vol est inférieur à 1000, avec une expérience limitée du vol en condition IMC réelle, particulièrement sur avion à hautes performances.

2.2. Séquences de vol

Tout se passe parfaitement bien dans la phase initiale du décollage, jusqu'à la rotation et la rentrée du train d'atterrissage. La trajectoire de vol est correcte ainsi que l'accélération.

Après avoir pénétré la couche nuageuse, peu après la rentrée du train et le message "airborne", la commande de profondeur est progressivement poussée vers l'avant, d'une manière de plus en plus saccadée, jusqu'à atteindre 40 % de la course vers l'avant.

La manette des gaz est ramenée de la position "plein post-combustion" vers "plein gaz sec" en suivant la procédure et à la bonne vitesse. Il faut aussi noter que l'inclinaison de l'avion est parfaitement contrôlée et que le cap ne varie pas plus de 2° pendant toute la séquence.

La poussée progressive sur la commande de profondeur a les effets suivants:

- Le facteur de charge décroît depuis approximativement 1G pour devenir proche de 0G (une valeur pic de 0,25 G négatif est enregistrée).
- la trajectoire culmine en altitude a environ 400-450 pieds AGL, puis commence à décroître de plus en plus rapidement. Depuis le moment où l'appareil entre dans la couche nuageuse jusqu'au sol, la trajectoire suivie est pratiquement balistique.
- Le facteur de charge demeure encore proche de 0G à l'approche de 100 pieds AGL. La commande de profondeur est brutalement ramenée plein arrière lorsque le pilote retrouve la vue du sol.

- A 100 pieds AGL, les paramètres de vol sont:

  incidence, environ 2°
  facteur de charge, proche de 0G
  pente, environ - 10°
  assiette, -8°

- Au moment de l'impact sur la piste on enregistre:

  incidence, 13°, croissante
  facteur de charge, + 3,5 G, croissant
  pente, - 10°, décroissante
  assiette, environ + 3°, croissante
  Vitesse verticale, environ 7000 pieds par seconde, décroissante.

La figure 2, qui présente les tracés de l'enregistreur de vol les plus utiles à la description de l'accident, résume la chronologie des évènements.

2.3. Analyse neurosensorielle

A partir des données issues de l'enregistreur de vol, il est possible de se faire une idée des stimulations agissant sur les macules otolithiques à différentes phases caractéristiques du vol. Ceci ne peut prétendre représenter l'image de la perception de la situation par le pilote, mais, dans ce cas précis, apporte des éléments qui permettent de mieux comprendre une partie des actions effectuées par le pilote, en particulier pour ce qui concerne la commande de profondeur. Comme le rapporte Gillingham (7), ce type de démarche a déjà été utilisé avec succès pour analyser des accidents où la suspicion de désorientation spatiale était forte.

Sur le tracé d'altitude présenté à la figure 2, quatre points caractéristiques ont été définis, correspondant respectivement à l'entrée dans la couche nuageuse (point 1), l'injection dans la trajectoire balistique (point 2), le point haut en altitude (point 3) et la sortie de la couche (point 4).

Pour ces quatres points, l'orientation de la force d'inertie agissant sur les macules otolithiques a été calculée, en faisant l'hypothèse simplificatrice que la tête du pilote (HPP) était strictement parallèle à la référence horizontale du fuselage. Les données d'accélération présentées (provenant des accéléromètres de bord) se réfèrent aux axes avion et les différentes forces sont rapportées dans un repère lié au sol (EVR, EHR). On peut donc définir, d'une part, l'angle d'orientation de la macule otolithique dans le repère terrestre (θ_V, supposé identique à l'assiette de l'appareil), d'autre part l'angle existant entre la résultante des forces massiques agissant sur cette macule et la verticale terrestre (θ_i) qui constitue la composante illusoire de la stimulation otolithique.

La figure 3 présente l'évolution de ces paramètres aux différents points précédemment définis, caractéristiques de la trajectoire. Au point 1 (fig. 3A), au moment de l'entrée dans la couche nuageuse, la stimulation otolithique induit une perception de cabré excessif, mais la désorientation ne semble pas encore patente puisque l'action sur les commandes est relativement normale pour la situation.

Notons ici que la rotation au décollage a été particulièrement prononcée (par rapport à des données provenant d'autres décollages), ce qui pourrait correspondre à un souci du pilote de traverser rapidement une couche nuageuse qu'il sait être peu épaisse, mais peut être aussi à réaliser un décollage "de performance". Quoi qu'il en soit, il corrige progressivement l'assiette initiale en poussant sur la profondeur. De ce fait, la composante d'accélération Jz diminue progressivement alors que le Jx demeure constant. Bien que l'assiette réelle soit revenue à 11° au point 2, la composition des forces agissant sur les otolithes indique une augmentation de l'angle θ_i, ce qui correspondrait à un effet sur l'assiette de l'appareil inverse à celui attendu (fig. 3B).

La désorientation latente devient alors patente et les actions sur les commandes sont alors plus saccadées, typiques du comportement d'un pilote désorienté, alors que la composante d'accélération Jz atteint 0G au sommet de la trajectoire parabolique (fig. 3C). Les automatismes cognitifs persistent cependant en dépit de la désorientation manifeste du pilote, puisque celui-ci coupe la post-combustion très précisément à 300 noeud, respectant ainsi scrupuleusement la procédure. Ceci implique donc une surveillance très étroite du paramètre vitesse, vraisemblablement en tête-haute.

Après l'arrêt de la post-combustion, la composante d'accélération Jx diminue considérablement, alors que l'appareil aborde la branche descendante de sa trajectoire parabolique. Au point 4 (fig. 3D), la composition des forces implique encore une stimulation otolithique conduisant à la perception illusoire d'une assiette positive. On peut cependant penser que le pilote est particulièrement inquiet de l'évolution de la situation, dans la mesure où son temps de réaction est extrêmement bref dès qu'il retrouve la vue du sol.

Notons enfin un point fondamentalement important pour cette analyse, qui comporte une part importante de spéculations, c'est que **l'ensemble de la séquence** depuis le levé des roues jusqu'à l'impact final n'a duré que **14 secondes**.

3. DISCUSSION

Il s'agit donc d'un accident dont le déroulement typique permet d'admettre avec une quasi-certitude l'existence d'une désorientation spatiale comme cause déclenchante. Ceci est d'autant plus probable qu'aucun défaut de fonctionnement de la machine n'a pu être mis en évidence, la seule anomalie constatée objectivement étant une erreur humaine mineure, l'horizon de secours n'ayant pas été décagé. En admettant que le pilote ait utilisé les informations de pilotage présentées dans le viseur tête-haute, conformément à ce qu'il avait appris à l'entraînement, une constatation s'impose: les informations d'attitude présentées dans le viseur n'ont soit pas été consultées, soit pas été "comprises" et utilisées. Dans les deux cas, il faut considérer le contexte de la pression temporelle très forte et de la contrainte émotionnelle résultant des conditions d'environnement. Ceci amène à envisager deux aspects , le premier lié à l'entraînement, l'autre à la symbologie de pilotage présentée dans le viseur tête-haute.

3.1. L'entraînement

La première idée qui vient à l'esprit lorsque l'on analyse cet accident est la mise en cause de l'expérience et de l'entraînement du pilote. On peut parler d'erreur de pilotage manifeste, avec une focalisation de l'attention sur la vitesse alors que les informations instrumentales d'attitude sont négligées au profit des sensations illusoires. Ceci est sans doute vrai, il s'agit d'un pilote relativement jeune dont l'expérience du vol sans visibilité est limitée.

Cette analyse brutale est cependant beaucoup trop superficielle et même si l'erreur humaine est manifeste vis à vis des standards classiques de pilotage, essentiellement cognitifs, elle doit être tempérée par des considérations d'ordre neurosensoriel. Il faut en effet réaliser que ces illusions sensorielles sont extrêmement puissantes et il n'est pas un pilote qui, un jour où l'autre, n'en ait pas ressenti les effets. En fait, la littérature scientifique et plus encore la tradition orale des forces aériennes de tous pays fourmille d'anecdotes diverses à ce sujet, survenues même à des pilotes très entraînés.

Pour l'heure, l'entraînement, donc la mise en jeu de processus cognitifs, demeure le moyen essentiel de surmonter les effets des perceptions d'orientation erronées rencontrées en vol. Il faut cependant bien considérer que ce fait n'est, sur le plan de l'orientation spatiale, qu'un palliatif qui révèle notre incapacité à fournir au pilote des informations sensorielles réellement adéquates à la tâche de pilotage.

3.2. Symbologie d'attitude

La faible valeur des informations d'attitudes présentées classiquement dans les viseurs tête-haute, tout particulièrement dans les situations évoluant très rapidement a été reconnue de longue date. Le faible champ couvert par ces informations, présentées en vision centrale avec une échelle unitaire est loin d'avoir la valeur des informations naturelles s'adressant à la vision périphérique et, d'un autre côté, ne permet pas de bâtir une représentation d'orientation d'une manière aussi satisfaisante qu'avec un instrument comme la boule. Dans le cas présent, les évolutions n'impliquaient pas une dynamique d'évolution de très grande amplitude, ce qui aurait pu permettre une utilisation correcte de informations d'attitude. Il semble bien pourtant qu'elles n'aient pas été utilisées, peut être en raison du décours temporel très bref, mais sans doute aussi parce que leur interprétation est loin d'être intuitive, même dans cette situation. Ces réflexions amènent à se poser un problème de fond qui touche au processus même de l'orientation spatiale, tant sous son aspect sensorimoteur que sur celui de la construction de la représentation mentale qui en est faite.

3.3. L'orientation spatiale: Aspects sensori-moteurs et représentationnels

L'étude des comportements d'orientation spatiale a été traditionnellement partagée entre deux grandes écoles qui, comme le souligne Paillard (11), se sont souvent opposées. D'un côté, les tenants de théories impliquant la transformation directe des entrées sensorielles en sorties motrices, dans la grande ligne de la réflexologie Sherringtonienne, de l'autre les cognitivistes insistant sur le rôle d'une construction mentale à l'origine des mouvements.

Bien que cette opposition soit aujourd'hui assez largement dépassée sur le plan scientifique, elle conditionne encore considérablement les approches qui peuvent être proposées sur le plan pratique pour améliorer la perception d'orientation spatiale en vol. Il ne semble donc pas inutile d'apporter quelques données récentes sur l'évolution de ce sujet.

De nombreuses tentatives ont été faites afin de mieux définir les différentes modalités d'orientation spatiale, en particulier en France où Paillard (11, 12) a proposé un moyen de réunir les aspects centraux et périphériques en postulant deux types de relations spatiales contribuant indépendamment à l'organisation nerveuse des comportements spatiaux. Il définit ainsi deux modalités différentes de traitement de l'information qui coexisteraient dans le cerveau, le mode sensorimoteur et le mode représentationnel.

Selon cet auteur, le mode sensorimoteur entretient un dialogue direct avec le monde physique au travers d'une connection directe de l'appareil sensorimoteur, contribuant ainsi au renouvellement continu d'une carte egocentrée de l'espace extracorporel, alors que le mode représentationnel dérive d'activités neurales explorant les représentations mentales de la réalité physique contenues en mémoire, permettant l'émergence d'un système stable de coordonnées allocentriques.

les deux modes opéreraient en parallèle, chacun utilisant ses propres voies neurales, générant et stockant sa propre cartographie de l'espace. Le choix de l'un ou l'autre mode pourrait dépendre du type de problème spatial à résoudre. Cependant, pour d'autres auteurs qui expriment des concepts proches (6), les deux modalités ne fonctionneraient pas vraiment en parallèle mais impliqueraient plutôt un procédé d'échantillonnage périodique. Ces conceptions suscitent un intérêt soutenu, en particulier pour tenter d'apporter des éléments quantitatifs concernant le mode représentationnel du comportement spatial, qui implique la cognition spatiale(8).

3.4. Approches possibles et perspectives

L'analyse des circonstances de l'accident aérien précédemment exposé, fait assez nettement apparaître que le comportement spatial du pilote a été essentiellement conditionné par une dominance de la modalité sensorimotrice sur la modalité représentationnelle. Les processus cognitifs mis en jeu par le pilote, contrôle de la vitesse, action sur la manette des gaz, respect des procédures, n'impliquent pas le problème de l'orientation dans l'espace environnant. Le problème est ici constitué par le fait que le processus d'estimation traitant les données sensorimotrices aboutit a une estimation d'état qui diverge de l'état vrai, en raison du poids des informations d'origine inertielle et de l'absence d'informations visuelles.

Deux voies d'action essentielles semblent donc ouvertes, en se fondant sur l'existence de deux modalités d'orientation coexistentes. L'une passe par le renforcement du fonctionnement de la modalité représentationnelle, non seulement par l'entraînement mais surtout par l'utilisation d'une symbologie utilisant au mieux les caractéristiques de ce mode, l'autre par la réalisation d'une **suppléance sensorimotrice** dont l'objectif serait de permettre l'obtention, dans le mode sensorimoteur, d'une estimation d'état cohérente avec la réalité physique.

3.4.1. Voie représentationnelle

Jusqu'à présent c'est dans cette voie que se sont développées les avancées les plus concrètes et efficaces dans le domaine de la présentation d'informations d'orientation spatiale. De nombreux auteurs ont contribué au développement d'une symbologie d'attitude optimale et il faut citer ici les travaux de Newman (10) et surtout les remarquables études expérimentales réalisées à l'IAM et au RAE, dont les prémices avaient été présentées par Taylor en 1984 (16). Les préoccupations actuelles semblent porter sur les mécanismes psychophysiques et neurophysiologiques impliqués dans la perception des informations présentées, avec une opposition entre les informations globales et locales (13). Weinstein et Ercoline (17) se sont pour leur part attachés à proposer une standardisation de la symbologie présentée dans les viseurs tête-haute.

Enfin pour certains auteurs, comme Menu et Amalberti (9) il semble nécessaire de privilégier les informations présentées au pilote dans un mode représentationnel de haut niveau, favorisant une résolution globale de la situation, plutôt que d'amener des données destinées à régler un problème ponctuel d'orientation spatiale. Il tempèrent cependant leur analyse pour les situations où la contrainte temporelle est très forte et la dynamique de l'appareil de forte amplitude.

3.4.2. Voie sensorimotrice

Bien que de nombreux auteurs se soient penchés sur le problème de la suppléance sensorimotrice, essentiellement visuelle, peu de réalisations pratiques réellement utilisables ont vu le jour et de nombreuses questions sont encore posées, comme le soulignent Christensen et coll. (5). La perspective d'apporter une information à valeur sensorimotrice directe est bien sûr extrêmement séduisante, et la voie de recherche la plus avancée, sans doute aussi la plus ancienne, porte sur l'utilisation de la vision périphérique. Il ne s'agit cependant pas d'une voie exclusive comme le souligne Rupert (15). Sur le plan technique, les problèmes majeurs sont constitués par la détermination des informations réellement pertinentes et la nécessité de les présenter avec une grande cohérence temporelle et spatiale, non seulement vis à vis du monde réel, mais aussi par rapport aux informations sensorielles d'origine vestibulaire.

3.4.3. Cohérence des informations

L'introduction de dispositifs de visualisation liés à la tête ouvre dans le domaine de la présentation d'informations d'orientation spatiale une problématique totalement nouvelle. Elle ouvre la perspective d'une utilisation d'informations adressant directement la modalité d'orientation sensorimotrice, par la présentation d'images capteurs du monde réel, mais aussi celle d'un risque de désorientation accru si la cohérence de ces informations n'est pas totalement maîtrisée.

Au delà de ce problème de cohérence de premier niveau, une question fondamentale se pose, comme le souligne Paillard (12). "Si nous devons admettre la coexistence dans les organisations biologiques, d'une part d'une machine **réactive,** directement soumise à l'action des contraintes environnementales......., d'autre part, d'une machine **projective** capable de différer ces réponses immédiates et de moduler ses actions en fonction d'un futur prévisible, il importe alors d'étudier pragmatiquement la manière dont ces deux modalités de fonctionnement interagissent, coopèrent ou même s'opposent à l'occasion dans la gestion des activités comportementales ou cognitives". Dans le domaine des visualisations, et tout particulièrement pour ce qui concerne les visuels de casque impliquant un contexte sensorimoteur particulièrement prononcé, c'est poser la question de la cohérence entre les informations " sensorimotrices" et "cognitives" qui, toutes deux, vont contribuer à la réalisation correcte de la tâche de pilotage. Il s'agit là d'un domaine très vaste et encore mal exploré, mais dont la connaissance est sans doute cruciale pour la mise en oeuvre optimale des visuels de casque dans leur fonction d'aide au pilotage.

4. CONCLUSIONS

L'analyse de cet accident montre donc bien clairement combien les illusions sensorielles peuvent avoir des effets puissants, amenant un pilote à opérer dans une modalité d'orientation spatiale sensorimotrice (réactive) plutôt qu'en utilisant le mode représentationnel (projectif) acquis lors de l'entraînement. La contrainte temporelle, le contexte émotionnel et l'expérience limitée du pilote constituent sans doute des éléments d'importance, sans qu'ils puissent être considérés comme totalement déterminants.

Apparemment, les informations visuelles d'attitude présentées dans le viseur tête-haute n'ont pas été utilisées ou n'ont pas été correctement interprétées, en tout état de cause n'ont pas suffi au pilote pour reconnaître la situation d'illusion sensorielle et la surmonter. Ceci pose directement le problème des caractéristiques optimales de cette symbologie et la connaissance des limites de la confiance que l'on peut apporter aux informations d'ordre purement cognitif dans la prévention de la désorientation spatiale.

Enfin, parallèlement aux actions qui sont menées dans le domaine de l'orientation spatiale cognitive et de la suppléance sensorimotrice, une voie de recherche importante est sans doute constituée par l'étude des relations entre les deux modalités d'orientation spatiale. L'utilisation optimale des possibilités offertes par les visuels de casque pourrait en effet dépendre fortement de la cohérence qui existera entre les informations relevant de chacune des modalités.

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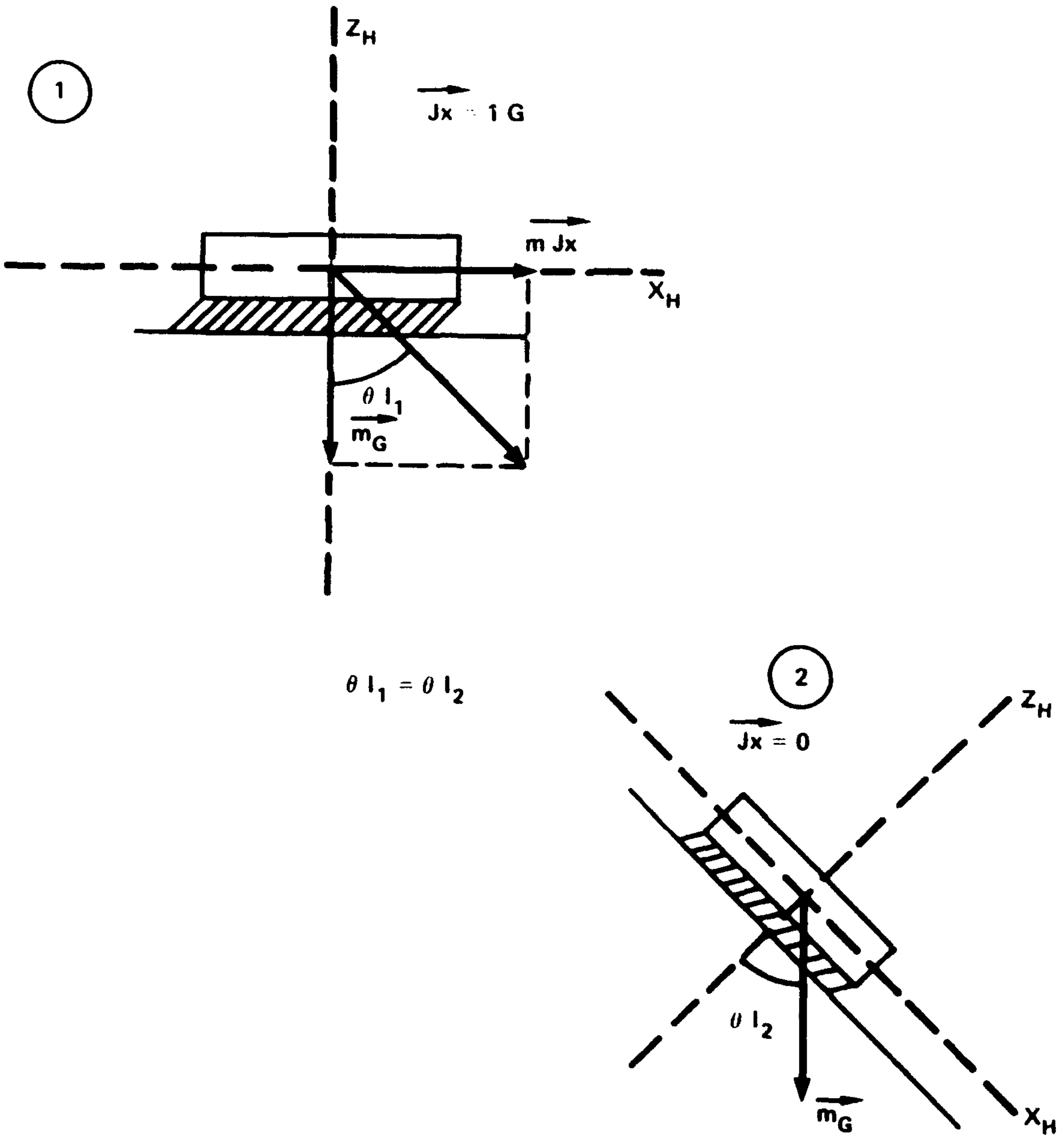

Figure 1 : Mécanisme de base des illusions somatograviques.

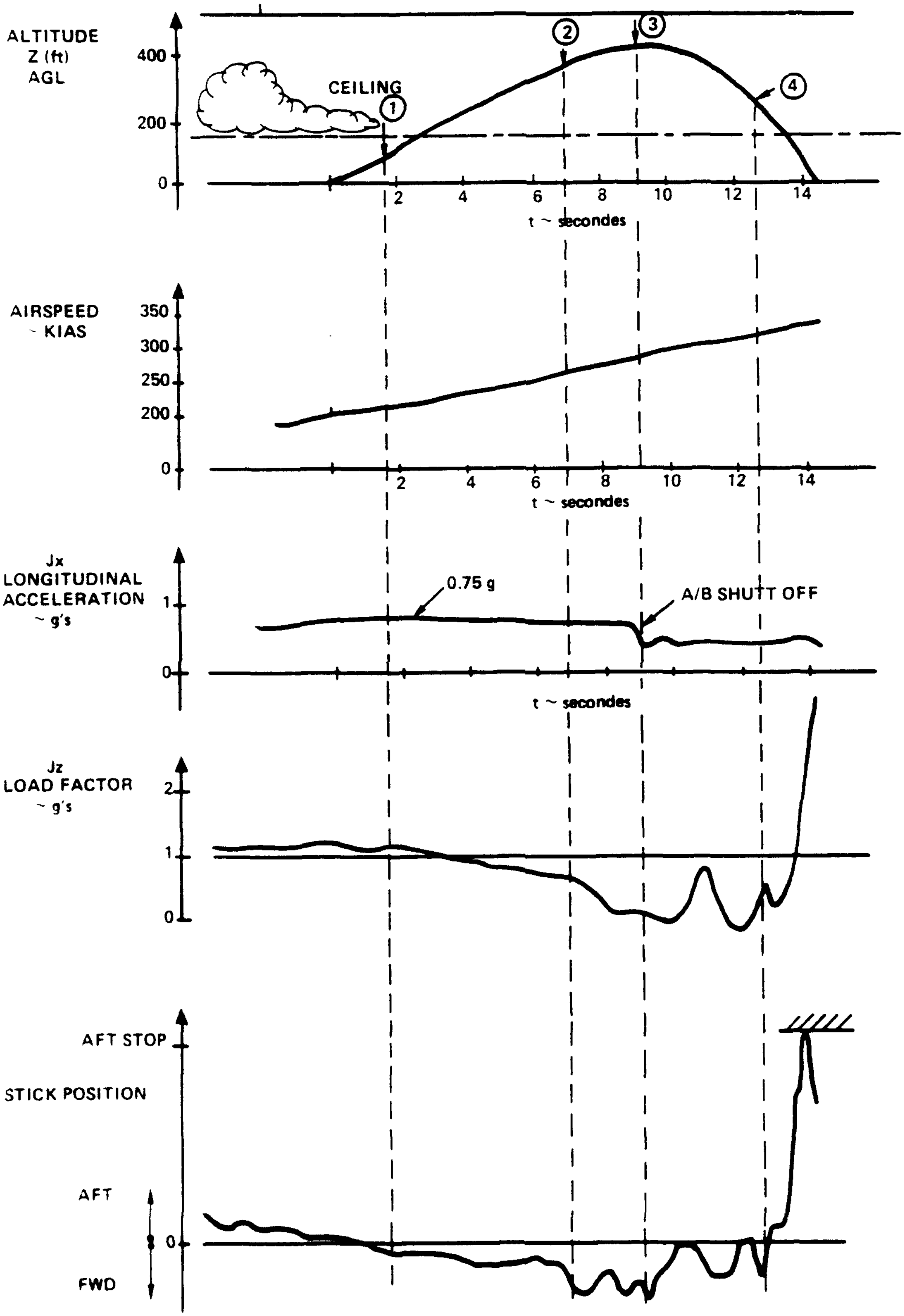

Figure 2: Séquences de vol. Les principaux paramètres du vol et les actions du pilote sur les commandes sont présentés depuis la rotation au décollage jusqu'à l'impact sur la piste

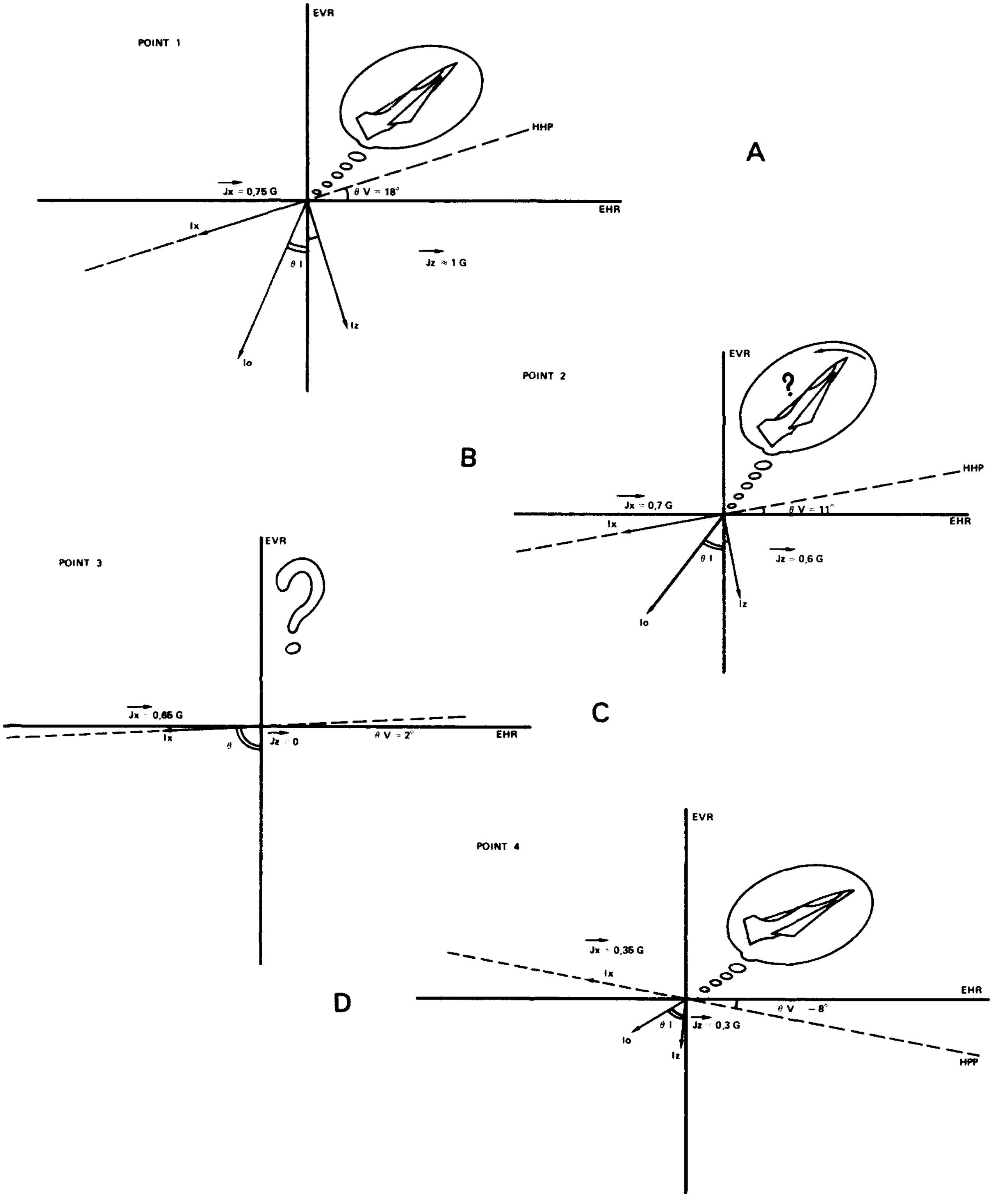

Figure 3 : Analyse neurosensorielle. A- au point 1 de la figure 2, après l'entrée dans la couche nuageuse le pilote perçoit un cabré excessif. B- point 2, l'action sur la commande de profondeur amène une réduction de l'accélération Jz, accroissant la rotation du vecteur inertiel résultant, l'assiette perçue augmentant paradoxalement.
C- point 3, passage à 0 Gz, désorientation complète. D- point 4, dans la branche descendante de la parabole la composition des vecteurs Jx et Jz aboutit encore à la perception d'une assiette positive.

LES FACTEURS COGNITIFS DANS LES ÉVÈNEMENTS AÉRIENS DE L'ARMÉE DE L'AIR AU COURS DE LA DERNIÈRE DÉCENNIE

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Summary : Accident prevention has been a continuous concern since the early beginnings of aviation. Early efforts in prevention have been devoted to system reliability, then to physiological factors. Improvements in both these directions lead to consider cognitive factors as the main source of accidents. Prevention efforts must take into account pilots' cognitive processes. In depth cognitive analysis of aircraft accidents serve to point out error mechanisms. Statistics complete this figure showing the respective occurence frequency of these mechanisms, therefore orient the preventive actions. Such an approach, focused on the cognitive factors involves to define a specific analysis grid from psychological theories on human error. The elaborated grid is the basis to design a cognitive oriented data base.

1. INTRODUCTION

La place des facteurs humains en tant qu'élément à part entière de la sécurité des vols n'est plus à démontrer. Que ce soit dans l'aéronautique civile ou militaire, elle représente autour de 70% des accidents. Les enseignements obtenus de l'analyse des compte-rendus d'accidents dépendent des méthodologies d'exploitation mises en œuvre. Mieux comprendre les mécanismes qui aboutissent à la production des erreurs humaines nécessite en particulier d'effectuer des analyses "en profondeur" des rapports d'enquête. On dégage ainsi des caractéristiques du raisonnement humain en fonction des circonstances de l'accident. Mais rapidement, il devient utile d'entreprendre une exploitation statistique de ces conclusions. Cette approche statistique n'est pas triviale puisqu'il faut rendre compte de mécanismes dépendant de leur contexte de survenue. L'élaboration d'une grille d'analyse qui permette d'exprimer le plus fidèlement possible toutes ces particularités devient le principal défi à la réalisation d'une banque de données. Parmi les bases de données existantes, rares sont celles qui prennent en compte les mécanismes cognitifs impliqués dans la production des erreurs. Ce papier vise à décrire la démarche qui a servi à l'élaboration d'une telle base de données. La première partie a pour objectif de montrer la place des facteurs cognitifs dans les facteurs humains responsables d'évènements aériens. La seconde partie décrit la démarche théorique qui a permis de définir la grille d'analyse pour exploiter les dossiers d'enquête. Dans la troisième et dernière partie, sont présentés les principes d'informatisation de la base de données.

2. PLACE DES FACTEURS COGNITIFS DANS LES ÉVÈNEMENTS AÉRIENS

2.1. Cadre de l'étude

Appréhender l'erreur humaine au travers des accidents aériens constitue un pari ambigu. En effet, on ne peut concevoir que les accidents soient la traduction de toutes les erreurs produites. Nombreuses sont celles qui ne portent pas à conséquence ou qui sont récupérées par leurs) auteurs ou encore qui passent inaperçues. Dans tous les cas, les mécanismes qui ont conduit à la production de l'erreur sont identiques. C'est au niveau des conséquences ou de la récupération que se "joue" ou non l'accident. Soit l'exemple d'un aéronef de combat qui accroche une ligne haute-tension : si l'avion s'écrase, l'évènement est classé accident, si le pilote ramène l'aéronef, il est classé incident or, les processus qui ont abouti à l'accrochage sont dans les deux cas identiques : soit une mauvaise préparation de la mission, soit le pilote qui ne regardait pas dehors ou soit le pilote regardait dehors mais il n'a pas perçu la ligne. Dans le cadre d'une approche statistique sur les mécanismes de production de l'erreur, l'intérêt est de collationner le plus d'évènements possible et de ne pas se limiter aux seuls accidents. Au sein de l'Armée de l'Air Française, des enquêtes similaires à celles des accidents sont menées pour les incidents graves n'entraînant pas de perte humaine ou de destruction d'aéronef. Prendre en compte les accidents et incidents graves permet d'enrichir la base de données, ils seront dénommés évènements aériens.

2.2. Les différents facteurs humains

L'analyse des dossiers d'enquête des accidents et incidents graves survenus dans l'Armée de l'Air Française entre 1980 et 1991 montre les points suivants (voir figure 1).

L'évolution de la responsabilité des facteurs humains dans la survenue des évènements aériens présente une courbe sensiblement parallèle à celle de l'évolution de la place des facteurs humains dans les accidents. On constate cependant des pourcentages plus élevés dûs à une prédominance des facteurs humains dans la survenue d'incidents graves par rapport aux accidents. Ces chiffres corroborent ainsi le fait que les seuls accidents ne reflètent qu'une partie des évènements où sont impliqués les facteurs humains. Prendre en compte les incidents graves permet d'en avoir une meilleure traduction, mais on peut penser que des études prenant en compte les incidents mineurs et les témoignages des pilotes permettraient une quantification plus réaliste. Le programme Aviation Safety Reporting System (ASRS) de la NASA (Reynard et al., 1986) et le programme de prévention des accidents de la compagnie aérienne française Air France (Gauthier, 1991) sont des exemples qui vont dans cette direction.

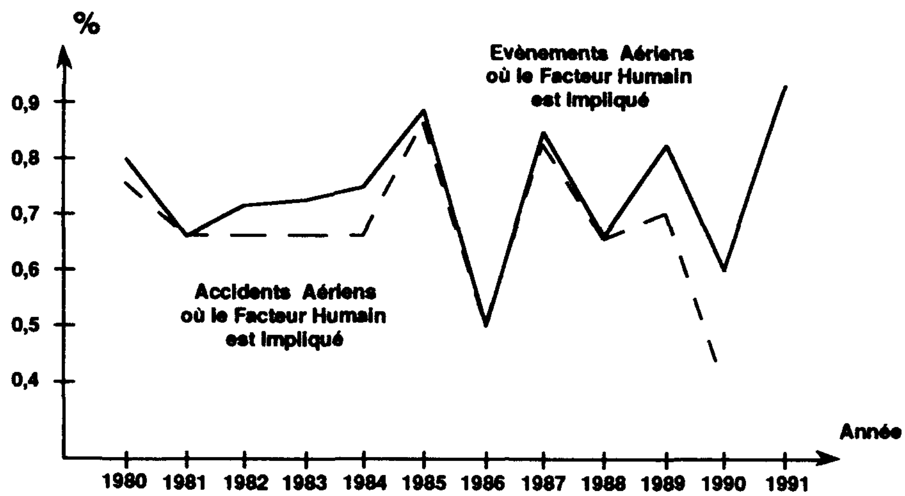

Figure 1. Place des Facteurs Humains dans les Evènements et Accidents Aériens de L'Armée de l'Air Française (1980-1991)

Les différents facteurs humains responsables d'évènements aériens se répartissent en (voir figue 2) :

- Facteurs médicaux, physiques ou toxiques : 6,5% des facteurs humains. Aucun facteur pathologique n'est incriminé, les causes toxiques le sont dans 1,5% et la fatigue dans 5%.

- Altération des capacités par application de contraintes physiologiques liées au vol : 2,5% des facteurs humains. Ils se répartissent en 2% pour la désorientation spatiale et 0,5% où une perte de connaissance sous accélération a pu être évoquée. L'analyse que l'on peut faire sur l'emploi des termes "désorientation spatiale" au cours de ces 12 années montre un manque de clarté dans la définition de ce concept. Menu et Amalberti (1989) ont précisé les différentes acceptions que l'on pouvait attribuer à ces termes. Ils parlent de désorientation spatiale pour qualifier tous les conflits intersensoriels générés par les contraintes physiologiques propres aux déplacements dans les trois dimensions ainsi que ceux déclenchés ou aggravés par des agressions physiques aéronautiques et qui ont des retentissements sur les mécanismes de l'orientation spatiale. Ainsi la perturbation de la vision périphérique sous hypoxie peut modifier les relations œil-vestibule dans l'orientation spatiale. Le résultat d'un processus de désorientation est la survenue d'illusion sensorielle voire de cinétose. Les mots "désorientation spatiale" sont employés ici avec ce sens.

- Inadéquation des processus de raisonnement : 87% des facteurs humains. Les processus de raisonnement se définissent comme les processus de prise d'information, de traitement de l'information, d'exécution des actions mais aussi d'élaboration d'un référentiel opératif commun (de Terssac et Chabaud, 1990) lors du travail à plusieurs (équipage, patrouille, guidage sous contrôle). L'ensemble de ces facteurs constituent les facteurs cognitifs. C'est dans cette classe de l'inadéquation des processus de raisonnement que Menu et Amalberti distinguent la capacité à comprendre l'évolution d'un processus dynamique. Cette compréhension aboutit à la notion de positionnement dans un environnement géographique puis tactique lorsque le pilote doit intégrer la situation tactique. On ne peut alors parler d'illusion sensorielle puisque c'est au niveau de l'interprétation de la situation qu'il y a problème et non de la fusion sensorielle. Cependant, nombreuses sont les confusions entre ces deux mécanismes fondamentalement différents et qui sont tous deux dénommés désorientation spatiale.

- Les 4% restants de facteurs humains dépassent le cadre de l'activité des opérateurs engagés dans la tâche de pilotage. Ils concernent les aspects de maintenance et permettent d'élargir le concept d'erreur humaine. Ce point sera abordé ultérieurement.

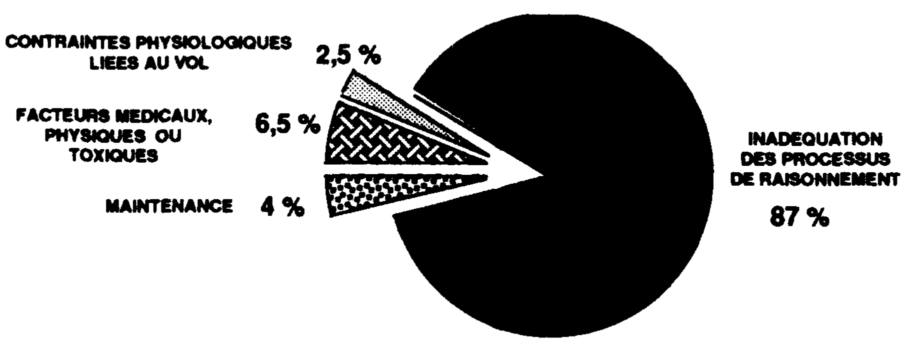

Figure 2. Répartition des Facteurs Humains responsables des Evènements Aériens

Cette répartition montre que le point-clé de la sécurité des vols est l'inadéquation des processus de raisonnement. Plus classiquement, toute cette catégorie représente ce que l'on appelle l'erreur humaine.

Pour aller plus loin dans l'analyse de l'erreur humaine, il est nécessaire de préciser ce que regroupe ce concept mais aussi d'en définir un cadre théorique.

3. BASES THÉORIQUES

3.1. Définir l'erreur humaine

Les définitions de l'erreur humaine sont multiples et loin de faire l'unanimité. Cependant, deux approches se distinguent dans la mesure où l'intérêt repose sur les mécanismes cognitifs. La première, la plus classique, consiste à considérer l'erreur comme un écart à la norme (Leplat, 1985). Cette définition présente l'avantage d'identifier clairement les erreurs mais elle pose le problème du choix de la norme de référence. Comme le précise Cellier (1990), 3 référentiels peuvent être choisis :

- celui de la tâche prescrite telle qu'elle est définie par les concepteurs.

- celui des opérateurs de la profession : toute situation de travail se caractérise pour les opérateurs par une adaptation de la tâche prescrite qui consiste en une redéfinition des buts. La référence est alors ce que fait un opérateur réalisant la mission et ne faisant pas d'erreur. Cette référence se distingue de celle des opérateurs qui sont reconnus comme "experts" par la profession, car l'expertise alors envisagée n'est pas obligatoirement adaptée à ce que sait faire le pilote. Amalberti et al. (1987) ont montré qu'à chaque niveau de qualification correspond une expertise différente, associée à des connaissances spécifiques, pour réaliser des buts effectifs différents.

- Le troisième référentiel est celui de l'opérateur lui-même, en tant qu'individu réalisant une tâche dans une situation particulière et qui se définit des buts spécifiques. On parle alors d'activité de l'opérateur.

S'il est facile de dire qu'il y a erreur puisqu'il y a eu accident, il est beaucoup moins facile de dire pour qui il y a eu erreur. Tout dépend du référentiel choisi. On rejoint là une distinction fondamentale faite entre une approche des accidents centrée sur la recherche de responsabilité qui fera référence à la tâche prescrite, et une approche préventive qui cherche à comprendre les mécanismes qui ont conduit à la production de l'erreur. Dans le cadre de l'élaboration de la base de données, l'erreur humaine est définie comme un écart à ce que font les opérateurs de la profession à qualification équivalente.

La deuxième approche de l'erreur humaine, proche du troisième référentiel consiste à introduire la notion de norme subjective et à donner à l'intention de l'opérateur un rôle central (Reason, 1990). L'erreur se définit comme un écart à l'intention. Beaucoup plus difficile à manipuler en tant que définition de l'erreur dans le cadre d'un rapport d'enquête, cette approche est plus opérative pour analyser les mécanismes cognitifs et comprendre la genèse de l'erreur.

3.2. Un cadre théorique de l'erreur en Aéronautique

L'élaboration du cadre théorique a 2 objectifs :

- définir une grille d'analyse des évènements aériens. Il est important d'utiliser une grille claire et exhaustive en en définissant bien toutes les rubriques (Nagel, 1988). Par exemple, les termes "focalisation, excès de confiance, manque de rigueur, technicité insuffisante, inattention et erreur de jugement" sont fréquemment rencontrés dans les rapports d'enquête. Or, ces termes ne sont pas définis avec précision et présentent le plus souvent une redondance. Bâtir une grille d'analyse sur de tels termes ne peut mener qu'à une impasse.

- rendre compte d'évènements aussi variés que ceux rencontrés. Si dans l'aviation civile, les profils de mission varient très peu, on ne peut en dire autant dans l'aviation militaire. Or, en raison du nombre des évènements qui surviennent dans l'Armée de l'Air Française, une analyse statistique ne peut s'envisager qu'à travers la prise en compte de tous les évènements : avions de combat monoplace ou biplace, avions de transport en mission tactique et avions école, pour ne citer que les principaux.

L'erreur humaine s'intègre dans un système à 3 dimensions :

- les faits qui représentent la description du processus et des comportements observables de l'opérateur.
- les facteurs initiaux ou aggravants
- les mécanismes d'erreurs

➡ Les faits sont les éléments objectifs de l'enquête. Ils font référence au type de mission, aux conditions de réalisation de la mission, à l'aéronef et à l'expérience aéronautique du pilote. L'établissement des faits propres aux déroulement de la mission dépend des sources d'information (présence d'enregistreurs de vol, richesse des enregistreurs, témoignage des opérateurs ou d'observateurs). Ils posent le problème du début de leur description et du niveau de granularité à adopter.

➡ Les facteurs se définissent comme des conditions qui peuvent favoriser ou aggraver la survenue d'une erreur. En effet, l'occurence d'une erreur n'est pas toujours liée à la présence d'un ou plusieurs facteurs, l'erreur pouvant s'expliquer par son seul mécanisme. La mise en évidence des facteurs est déduite des faits. En ce sens, les facteurs sont objectifs mais leur implication dans le déroulement d'une situation incidentelle est beaucoup plus inférentielle.

La notion de facteur peut être illustrée en prenant l'exemple de l'environnement pauvre en stimulus visuel pour évaluer la hauteur dans un vol basse altitude (survol désertique). Pour tous les pilotes et dans le même environnement, les informations visuelles sont identiques. L'analyse des informations est un mécanisme actif qui dépend de la représentation qu'a le pilote de la situation. Seule une représentation considérant que la hauteur n'est pas potentiellement conflictuelle, amènera le pilote à ne pas traiter finement les indices sensoriels ou à ne pas adopter des stratégies différentes de pilotage (pilotage plus centré sur les instruments par exemple). Le facteur "pauvreté des indices visuels relatifs à l'appréciation de la hauteur" n'est pas la cause de l'accident mais par contre il a pu déclencher ou aggraver un mécanisme cognitif conduisant à l'erreur.

La connaissance des différents facteurs et leurs implications probables constituent des moyens directs d'améliorer la sécurité des vols. Cinq catégories de facteurs peuvent être identifiés :

- les facteurs médicaux et physiques : pathologie, toxique, fatigue...
- les facteurs physiologiques liés au vol : hypoxie, hypobarie, accélération...
- les facteurs psychologiques : personnalité, motivation, stress...
- les facteurs environnementaux : visuel, sonore, thermique, météo...
- les facteurs de communication : média, leadership, langage opératif...

➡ Les mécanismes d'erreurs traduisent les processus cognitifs qui ont conduit à la survenue de l'erreur. Leur identification résulte d'une démarche inférentielle faite par l'analyste en raison bien souvent de l'absence de données suffisantes dans le rapport d'enquête mais aussi en raison de la part non consciente de certains de ces mécanismes. On en distingue quatre :

- les ratés d'exécution. L'opérateur a une intention adaptée à la situation mais les actions qu'il effectue sont incorrectes. Les ratés surviennent dans les tâches routinières et fortement automatisées où l'activité de l'opérateur est basée sur des habitudes. Le raté s'explique par une capture attentionnelle qui entraîne une défaillance du contrôle de l'action. Un exemple typique de raté est le pilote qui, après s'être posé, veut sortir les aérofreins et rentre le train, les deux manettes étant l'une à côté de l'autre. On retrouve dans ces erreurs les "finger-errors" décrites par Wiener (1986).

- Les fautes traduisent un échec des processus de jugement, d'inférence et de planification indépendamment de l'exécution des actions. Deux catégories de fautes peuvent être décrites : les fautes que Reason (1986) décrit comme consécutives à une "rationnalité limitée" et les fautes par manque de connaissances.

Le principe des fautes par "rationnalité limitée" repose sur les capacités limitées qu'a l'opérateur en tant qu'être humain de traiter l'information. Confronté à des situations complexes, l'opérateur grâce à 2 mécanismes de recouvrement cognitif (la comparaison par similarité et la spéculation sur la fréquence) tente de simplifier la réalité et de ramener la situation à une situation connue. Reason attribue à ces mécanismes de recouvrement la faculté qu'a l'opérateur d'évoluer dans son environnement. En contre-partie de cet avantage, ils peuvent générer des erreurs liées à l'imprécision que leur fonctionnement entraîne. Les erreurs générées portent en aéronautique sur 3 domaines :

• une mauvaise représentation de l'environnement, par exemple la mauvaise appréciation d'une hauteur ou d'une distance.

• une mauvaise représentation de l'état avion que ce soit lors d'une panne réacteur ou lors de l'utilisation des systèmes embarqués.

• une mauvaise représentation des actions à mener en termes de stratégies ou de choix de conduite : utilisation des modes du sytème de navigation ou choix de pilotage à vue par exemple.

Les fautes par manque de connaissances consistent en l'emploi de règles ou procédures inadaptées aux intentions de l'opérateur : soit parce que la procédure est erronnée, soit parce qu'elle est correcte mais ne correspondant pas à la situation, ou soit la procédure est connue mais non appliquée.

- Les indisciplines reflètent une intention délibérée de l'opérateur de sortir du cadre de ce que font les opérateurs (confère la définition de l'erreur humaine donnée précédemment). Les exemples de tels comportements sont multiples en aéronautique (passage à basse altitude au-dessus de la maison d'un ami qui se termine tragiquement). Dans ces cas, les buts que se fixe le pilote sortent du cadre de sa mission et ne visent qu'à contenter des satisfactions personnelles.

- Les erreurs par non élaboration d'un référentiel opératif commun. Ces erreurs font appel à des mécanismes décrits dans les fautes mais la relation sociale due à la présence d'un ou plusieurs opérateurs introduit d'autres mécanismes. En effet, le référentiel opératif commun s'élabore à partir d'une représentation de ce qu'on pense que l'autre sait et de l'image sociale que va générer son propre comportement. Un exemple classique de barrières sociales qui peuvent s'installer dans un cockpit est représenté par le cas où le commandant de bord et le copilote ont une qualification et une expérience équivalentes : aucun des membres d'équipage n'osera s'exprimer face à une situation qui se dégrade pensant que l'autre interviendrait s'il y avait un problème potentiel ou que l'avis que l'on peut donner n'est pas de circonstance. La situation peut alors se poursuivre jusqu'à l'incident bien que les membres d'équipage pressentent une situation conflictuelle.

Parmi les 87% d'erreurs dues à une inadéquation des processus de raisonnements, ces différents mécanismes d'erreurs se répartissent de la façon suivante (voir figure 3) :

- 9% pour les ratés d'exécution.

- 48% pour les erreurs par "rationnalité limitée" dont 16% pour les mauvaises représentations de l'environnement, 10,5% pour les mauvaises représentations de l'état avion et 21,5% pour les mauvaises représentations des actions à mener.

- 25% pour les erreurs par manque de connaissances.

- 6,5% pour les indisciplines.

- 11,5% pour la non-élaboration d'un référentiel opératif commun.

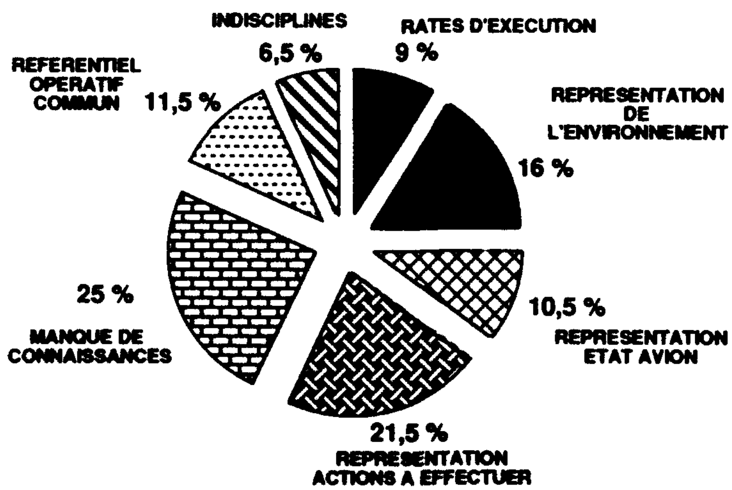

Figure 3. Répartition des Erreurs par Inadéquation des Processus de Raisonnement

L'intérêt de ces premiers résultats est de montrer l'adéquation du cadre théorique au contexte aéronautique. Tous les mécanismes décrits constituent une part non négligeable dans la survenue des évènements aériens. Les efforts pour améliorer la sécurité passent par une prise en compte de tous ces mécanismes à travers des classifications des faits et des facteurs qui y sont associés. Ces données sont en cours d'intégration dans la base et devraient permettre d'ici peu des exploitations systématiques.

3.3. L'erreur en amont du pilote

L'erreur a longtemps été envisagée au niveau du pilote ou des différents opérateurs impliqués dans la réalisation de la tâche (navigateur, contrôleur), mais la sécurité des vols concerne aussi des opérateurs et des hommes qui sont en amont du pilote. Ceux qui viennent le plus rapidement à l'esprit sont ceux impliqués dans la maintenance et ils représentent 4% des facteurs humains (voir section 2.1.). Mais l'erreur humaine peut se situer bien en avant. On parlera de globalité de l'erreur. Or, à chaque niveau précédant le pilote, tout est fait pour que l'erreur soit minimale. Une règle de cette succession de niveaux consiste à suppléer par une couche les erreurs que l'on n'a pas pu supprimer à la couche précédente. En schématisant, on peut décrire les couches suivantes : définition de la tâche, choix de conception, organisation, matériels, règlementation et en dernier l'opérateur, c'est à dire le pilote. Dernier maillon de cette succession de couches, le pilote a pour charge de récupérer les erreurs qui n'ont pu être évitées aux niveaux précédents. Il remplit cette fonction grâce à ses capacités d'adaptation qui le rendent irremplaçable. En contre-partie, et nous l'avons vu, il est possible qu'il échoue. Dans ce cas, une approche systémique permet d'étudier les différents niveaux et non pas de se focaliser sur le seul pilote. Toute démarche s'inscrivant dans l'amélioration de la sécurité des vols doit prendre en compte ces éléments.

4. LA BASE DE DONNÉES INFORMATISÉE

La base de données informatisée est construite à partir de la grille d'analyse décrite ci-dessus (voir figure 4). Elle est sur un Micro-ordinateur Mac Intosh LC d'Apple dédié spécifiquement. La base est réalisée à l'aide d'un logiciel de traitement de données. Le logiciel "Quatrième Dimension" d'A.C.I. a été choisi en raison de ses qualités pour représenter le formalisme que nous venons de décrire, des nombreuses possibilités qu'il offre pour exploiter les données et de son interface convivial. Le principe de "Quatrième Dimension" est de constituer une base de données relationnelle : c'est-à-dire, définir des concepts avec leurs attributs et mettre en relation ces concepts pour établir un graphe. Ce graphe permet, d'une part, d'insérer toutes les données obtenues lors de l'exploitation des dossiers et, d'autre part, d'envisager des sorties multiples lors de l'interrogation de la base.

Le schéma représente l'ensemble des différents concepts de la base. On y distingue les mécanismes psychologiques, les différents facteurs et les faits qui sont représentés par les concepts "conditions accidents" et "personnels".

5. CONCLUSION

La démarche suivie s'inscrit dans une approche préventive de l'erreur humaine basée sur une meilleure compréhension des mécanismes cognitifs. Cette meilleure compréhension passe par une analyse plus large que celle des seules analyses "en profondeur". Elle ne peut se faire que par une exploitation informatisée des données afin de dégager des enseignements sur l'évolution des facteurs et des mécanismes cognitifs d'erreur par rapport aux générations d'aéronefs en service ou à la formation et à la carrière des pilotes. La bonne réalisation d'un outil informatique est alors un point-clé pour assurer la cohérence et la continuité des analyses. L'intérêt d'un tel outil est en relation directe avec les préoccupations ergonomiques de notre division pour faciliter la correction de systèmes existants, l'élaboration de nouveaux systèmes et la formation des pilotes.

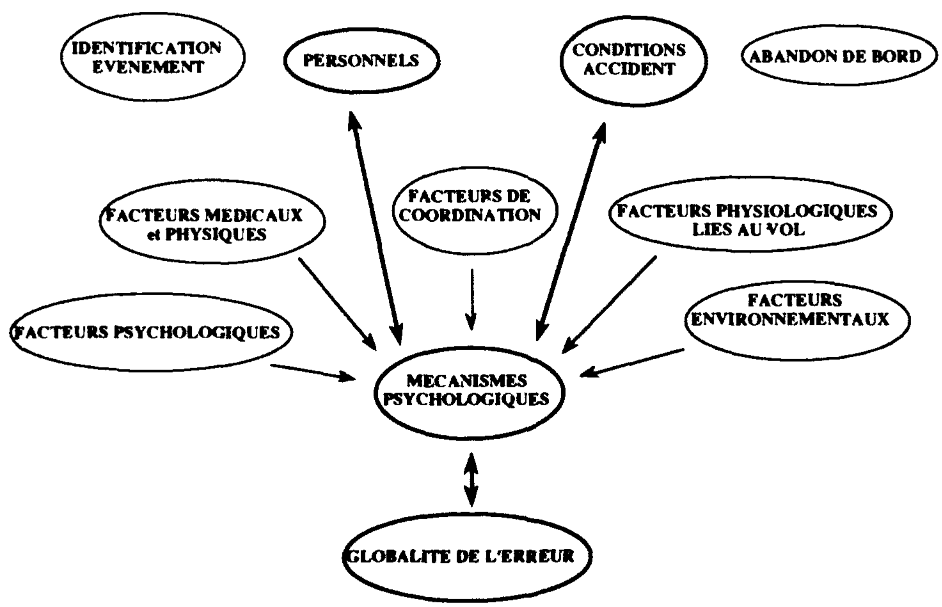

Figure 4. Graphe Relationnel de la Base de Données

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EFFECTS OF MEDIUM BLOOD ALCOHOL LEVELS ON PILOTS'PERFORMANCE IN THE SEA KING SIMULATOR MK-41

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Summary:
A number of 20 military pilots drank certain amounts of alcohol until the blood alcohol concentrations reached a level of about 0.8 o/oo. After that they had to fly IFR mission using the flight simulator for 2 1/2 hours. They were told to perform the complete program of navigation and flight operations and also communication with for example air traffic control (ATC). During the simulated flight programmed technical failures occurred concerning the instruments and the engine. The reactions of pilots and the cause were registered. The results were obtained by summarizing false reactions. Significant differences in the number of wrong reactions due to alcohol consumption were registered.

Introduction:
In most of the experimental examinations of the effects of alcoholic intoxication the test persons had to accomplish a "Single Task" or "Double Tasks" (for example, center line and glide pass control during an ILS approach). So only one or two tasks had to be performed which called for concentration and psychomotoric coordination.

Obviously, these methods allow only statements about the effects of single or double psychophysical strains.

Extrapolations and statements on the overall performance in case of more complex tasks such as flying an aircraft can be made only in a very general and superficial sense.

Flying an aircraft, however, is a multifunctional activity and requires considerably more manual activity than driving a car. Under extreme conditions - occurring in the past while flying the F-104 - the pilot was forced to take decisions every 1.5 seconds on average.
To make statements on the degradation of the overall performance, an examination under real flight conditions - that is under functional integrity - would be required. However, flights of intoxicated pilots must be ruled out and the results gained under an artificial test environment (single/double task) are not so comprehensive as to allow an overall assessment.

Using a flight simulator is the only chance to realistically generate all events during the movements of an aircraft.

We now would like to report our experience with such a simulator.

Setup of the experiment:
20 professional pilots had to consume an amount of 0.8 g alcohol per kg body weight within one hour to the effect that blood alcohol concentrations of up to 0.08 percent were achieved. Each of the crews had then to carry out a 2.5-hour IFR flight in the completely equipped, hydraulically movable SEAKING helicopter cockpit of the MK-41 simulator. The reactions of the intoxicated pilots were compared with the reactions of the same pilots not under the influence of alcohol on a similar difficult flight.

The flights were supervised on a flight instructor control panel which showed all the cockpit instruments and, in addition, displayed flight tracks and operational readiness of the helicopter systems on screen. The supervising instructor also played the role of the ground control stations.
The test was primarily intended to assess the alcohol-induced performance degradation prevailing in specific areas under the overall strain of the flight.
One mission, for example, consisted of a night flight from Hanau over Frankfurt, Finthen, Coleman, Serbach, Ramstein to Pferdsfeld. After the take-off the altitude hold broke down for the entire duration of the flight. The route initially led to Hanau NDB, Metro VOR to Frankfurt where an ILS approach on runway 25 was ordered. Different altitudes had to be maintained between the two beacons. Increased air traffic required a holding over the Metro VOR until the approach clearance was given. The situation was aggravated by the failure of the entire automatic stabilization during holding and ILS approach. The ILS approach was carried out as planned. During the overflight the crew received a comprehensive further clearance covering several check points all the way up to Finthen. One of the check points was the IF intersection Vinti which was, however, not entered in the navigation map but only on the approach chart for Finthen. The pilots had to maintain different altitudes between the various check points. After finishing the approach the crew had to continue their flight with STAB-ON, that is with automatic stabilization. The second ILS approach in Finthen was executed as planned in the form of an NDB approach on runway 08. During the turn to the center line both artificial horizons were blocked

on the slant. The crew had now to execute the whole approach with their stand-by horizon and altitude indicator.
After finishing the approach both horizons were operating properly again. The crew received a comprehensive further clearance directing them to an intersection. To approach the intersection, a radial from Frankfurt to Vortac had to be flown and maintained. Increased air traffic, however, required the crew to fly a waiting loop radial/fix in non-standard holding. From there a further clearance inbound Coleman was given and a VOR/NBD approach executed on runway 05. During the approach the automatic FSC had a malfunction forcing the helicopter into an anomal flight attitude. The crew had then to take over manual control whereby the pitch stabilisator broke down. During the flight over Coleman a further clearance towards Sembach was received with an IAF for a TACAN approach on runway 07. At an altitude of 4000 ft. one of the front fuel pumps failed, initially without consequences. Shortly later, however, also the generator #1 broke down causing the failure of the second front fuel pump and the second rear fuel pump; leading to an overall malfunction of engine #1, that means to a flameout.

For explanation: Following the malfunction of the fuel pump a baffle valve had to be opened in order to avoid the flameout. If the breakdown of the engine had not been prevented, Sembach was the ultimate destination of the flight.
This example shows the large extent of the navigation work required by the crews such as precise approaches to check points, altitude and course changes in holdings, and various landing and go-around procedures. These tests were made more difficult by temporary failures of instruments or erroneous beacon signals, changes in wind direction and force, and failures of important helicopter equipment assemblies such as fuel pumps and the automatic FCS, finally ending in the flameout of an engine.

Depending on their flight experience, even non-intoxicated pilots would have to make an all-out effort to master such problems.

<u>Results:</u>
The reactions of the intoxicated pilots were compared with those reached by the same pilots not under the influence of alcohol in a similar difficult flight. We assessed three different categories of activity:

1. Handling of radio communications
2. Navigational performance
3. Helicopter control and observation of instruments

After collecting the relevant data of all test series, we came to the following results:

- Mistakes in the operation of control instruments and communication devices occurred more frequently under the influence of alcohol.
- Prescribed messages were not always transmitted no matter whether or not the pilots were intoxicated. The communicative understanding was considerably restricted under the influence of alcohol.
- The pilots performed worse in certain flight procedures e.g. (approach, holding).
- The influence of the wind was almost permanently underestimated.
- All pilots went through the check lists incorrectly; under the influence of alcohol this deficiency occasionally led to major flight errors (for example, non-retracted landing gear in flight).
- Altitudes and courses were also incorrectly maintained. Under the influence of alcohol, however, several crews got completely lost.
- The control of the helicopter either with functioning or defect supporting systems was limited under the influence of alcohol.
- Intoxicated pilots did not watch their instruments correctly and, therefore, failed to timely recognize occurring errors.
- Only the error rate of very experienced pilots did not increase. Pilots with average or less flight experience, however, were considerably impaired by the influence of alcohol.
- In addition, a certain negligence in transmitting prescribed messages and handling check lists became obvious. Intoxicated pilots frequently had a muddled way of speaking and mixed up figures.
- In some cases, the co-pilot made the pilot aware of errors which only then were corrected.

<u>1st category:</u>
The supervising instructor listened to the radio traffic, assessed the speed of speech and variations in the way of speaking, and counted the occuring communication problems.

Communicative errors and misunderstandings occurred under the influence of alcohol. During the first hour of flight, we also frequently noticed a slower and considerably muddled and offhand way of speaking and a loose mood in talks.

In five cases the clearances given by the ground radio station had to be repeated in full. One of the crews was even unable to understand and repeat the meaning of a further clearance though the message was transmitted several times. This fact resulted in a gross impairment to flying safety. All other errors of this category had no immediate consequences.

<u>2nd category:</u>
Major errors occurred in the navigation of the helicopter. Once a holding was flown on the wrong side, another time along an offset course. In three other cases disorientation prevailed (slide). One crew flew to a wrong initial approach fix on the airway. During one flight the position of the radio compass needle was misinterpreted to the effect that the pilot confounded the sides. Another crew followed a wrong approach course to the airfield. Finally, the deviation from the planned approaches to certain IAFs on the airways reached up to 7 nm which considerably ex-

ceeded the margin achieved in the tests with the pilots being sober. In four cases, navigational errors led to dangerous situations.

3rd category: Helicopter control

Apart from minor errors which were made by sober pilots as well, big mistakes occurred under the influence of alcohol which would doubtlessly have jeopardized the flying safety or caused a near crash. In one case the pilot fell considerably below the prescribed minimum speed during a landing approach. In another case, the pilot failed to recognize that he had already left the airfield far behind him but nevertheless continued his letdown. One crew forgot to lower the landing gear and another crew fell considerably short of the cruising speed resulting in a near crash.

Apart from these errors, the emergency procedures provided for in case vital equipment or engines fail were always mastered even under the influence of alcohol. It was interesting to note that - despite the breakdown of the automatic FCS - one of the ten crews sticked under the influence of alcohol more precisely to the prescribed glide path and course than it had done otherwise.

Conclusions:

It is to note that major errors regularly occurred in radio communications, navigation and helicopter control which occasionally endangered flying safety.

Sober pilots with great experience, that is with more than 2500 flight hours, had, if at all, only a slightly increased error rate under the influence of alcohol.

Less experienced pilots, however, with a total of 1500 flight hours or below, performed significantly worse, if not completely disoriented, under the influence of alcohol than otherwise.

So we may conclude that in addition to a possible intoxication of a pilot also his proficiency plays a very important role in the investigation of aircraft accidents.

Final notes:

1. Pilots with a blood alcohol level below 0.1 g per ml usually made mistakes in communicating over radio and in controlling the helicopter and so jeopardized the flying safety.
2. Pilots with a very comprehensive and long-lasting experience showed, if at all, only a slight performance degradation under the influence of alcohol.
3. The crews never failed to execute the emergency procedures correctly even under the influence of alcohol.

ROYAL NAVAL HELICOPTER DITCHING EXPERIENCE

by

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Summary

Controlled or uncontrolled water entry (ditching) by Royal Naval helicopters continues to occur and is a significant loss of resource - both human and aircraft. Accidents over a ten year period (1982-1991) are listed, causation and trends analysed, and preventative measures put forward, as are initiatives to increase post ditching survivability.

Key words - Helicopter, accidents, disorientation, survivability.

Introduction

Any malfunction, either minor or catastrophic, in a helicopter flight over water, may result in either a controlled or uncontrolled ditching. Several factors may influence this. These include:

- Distance from land - where the malfunction precludes any transit to a landing on terra firma.

- Embarked flying from ships, where the malfunction may preclude any transit time or the size and characteristics of the landing platform is unsuitable for the type of landing required by the malfunction.

- Flight profile - altitude, in forward flight, or in the hover.

- The associated sea state.

- Day or night flying.

Maritime Environment

Two examples will illustrate this. A loss of tail rotor control in the hover at night under high power (torque) conditions will result in an uncontrolled ditching with probable immediate inversion of the helicopter, whereas in forward flight over land either a running landing or an autorotation should lead to a successful outcome for both crew and machine. Similarly, any engine malfunction in a twin engined helicopter hovering outside its single engine performance parameters will result in a reasonably controlled water entry, the outcome of which will depend on the flotation characteristics of the helicopter and the prevailing weather conditions; whilst in forward flight no major consequences should result.

Thus given the inhospitable environment the overall objectives must obviously be to minimise the chances of a ditching by preventative measures, but since in practice this cannot be guaranteed, additionally to maximise the chances of a successful egress by the crew from an inverted helicopter with the crew compartment submerged.

Ditchings

Royal Naval helicopter accidents have recently been reviewed (1, 2, 3), and a complete overview of British military helicopter ditchings has recently been completed (4). It is not therefore intended to re-state these findings here. Rather, an analysis of a ten year period of Royal Navy ditchings, from 82 to 91, has been performed. Simple tabulated results show no new lessons, only to re-emphasise that where the ditching has occurred in a relatively controlled fashion, crew survivability is good.

However this basic information can be improved by plotting it in this format:

No human error	Human error
|--|	
Mechanical failure	No mechanical failure

If the tables are subdivided, Table 1 gives accidents due solely to catastrophic mechanical failure and Table 2, those due to aircrew error with no aircraft malfunction.

Date	Aircraft	Remarks
12.05.82	Sea King 5 ZA132...	Engine failure in hover.
11.07.82	Sea King 5 XV698...	Engine failure in hover, other engine failed to respond.
30.09.82	Lynx XZ247...........	Fire in main gearbox.
28.10.82	Wasp XS568...........	Engine failure.
04.05.83	Lynx XZ249...........	Tail rotor control failure.
27.05.83	Wasp XV638...........	Oil pump failure.
20.06.83	Sea King 5 ZA130...	Tail rotor control failure.
06.09.83	Wasp XT427...........	Partial engine failure.
13.04.84	Wasp XT794...........	Partial engine failure.
29.09.84	Sea King 5 ZA134...	Engine failure in hover.
05.03.85	Wasp XT423...........	Engine failure.
05.11.85	Sea King 5 XZ918...	MRGB lub failure.
26.10.86	Sea King 5 ZD632...	Fuel starvation.
03.02.88	Sea King 5 XV652...	Tail rotor drive failure.
27.10.89	Sea King 5 XZ582...	MRGB lub failure.
01.06.90	Lynx XZ734...........	Harpoon failure, rolled off deck.
10.09.90	Sea King 6 ZD631...	MRGB lub failure.

Totals: Ditchings - 17
Fatalities - Nil

Note: MRGB - Main rotor gearbox

Table 1 - Catastrophic Mechanical Failure

23.04.82 Sea King 4 ZA311 - 1 Flew into sea at night during high workload, single pilot operations.

19.05.82 Sea King 4 ZA294 - 21 Descended into sea at night during high workload, single pilot wartime operations with minimum visual cues at very high AUW.

03.02.83 Sea King 5 XV658 - 1 Flew into sea during mis-judged wingover manoeuvre.

16.10.85 Sea King 2 XV672 - Fuel exhaustion, mis-identified mother ship.

10.03.88 Lynx XZ243 - 2 Descended into sea during mis-judged, abbreviated night approach to ship while short of fuel.

01.06.91 Sea King 5 XZ577 - Hit ship during mis-judged fly past.

Totals: Ditchings - 6
Fatalities - 25

Table 2 - Aircrew Error, No A/C Malfunction

However these extremes do not account for all accidents, and another table, Table 3, annotates those with an aircraft malfunction with an inappropriate response by the crew.

18.05.82 Sea King 5 XZ573 - Rad alt failure in night hover mishandled.

24.03.87 Sea King 5 XV668 - 3 FCS malfunction during high workload night hover in very poor conditions overwhelmed crew's flying ability. A/c crashed nose first into sea.

13.10.88 Sea King 5 XZ916 - 2 Minor u/carriage malfunction distracted pilots, a/c flew into sea 30 secs after night launch from ship.

Totals: Ditchings - 3
Fatalities - 5

Table 3 - A/C Malfunction, Inappropriate Response

Relevant factors will now be discussed.

Mechanical Failure

The Sea King anti submarine fleet will remain in service for some years yet, with the requirement for all weather day and night operations at the hover under high power conditions for long periods. From Table 1 it can be seen that failures associated with the main rotor gearbox in the Sea King continue to occur, and with the requirement for an immediate "landing" as a consequence of the gearbox's inability to continue running safely dry, or without oil, there remains the possibility of loss of aircraft and crew. Incidents involving gearbox malfunctions are to a great extent associated with a failure of oil pressure, or the high speed input shafts from the engines.

Civil Sikorsky S61s and US Navy Sikorsky SH3s are fitted with an emergency lubrication system which allows 30 minutes of flight, which is usually sufficient to at least carry out a pre-planned emergency water landing if unable to reach a landing platform.
Royal Naval Sea Kings are being modified in two areas. First, a more sophisticated emergency lubricating system is being installed, which will involve an additional sump and separate pipework. Second the bearings on the high speed input shafts are being modified to allow reduced lubrication demand and greater tolerance to total failure of oil supply.

These two together should provide much improved safety performance, with an excess of two hours emergency running time.

Figure 1 : Mécanisme de base des illusions somatograviques.

This will not only decrease the possibility of unwanted ditchings, but also in the worst case give ample time in descents from altitude before a final catastrophic gearbox failure.

Disorientation

At the other end of the scale in Tables 2 and 3 are instances whereby a perfectly serviceable aircraft is flown into the sea through human error or through an inappropriate response to a containable malfunction. The major causation is through disorientation. More worrying, although disorientation was only cited in 23% of the accidents, because of the speed and high impact forces involved it accounted for 85% of fatalities. Ninety per cent of all fatalities through disorientation could be attributed to inadvertent loss of height.

The maritime helicopter environment is well known for its potential to induce disorientation, and causes and effects have been well documented (3, 5, 6, 7). However, despite aircrew being very aware of its insidious onset and nature, and of the correct recovery actions, incidents continue to occur. A typical recent example is:

"On over-shoot at 100ft 100kts 30 degree angle of bank with Rad Alt hold engaged pilot glanced up to ensure flight path clear. On return to instruments height noted to be 30ft and descending. Aircraft levelled at 10ft before recovery effective. Aircraft returned for uneventful landing".

Peripheral Vision Displays

There are two types of human visual information processing pathways, one involving central vision, and the other peripheral vision. The latter does not involve central processing and is the main input for human orientation. Mindful of this, Malcolm developed a peripheral vision device (PVHD or "Malcolm" horizon) which utilised a gyro stabilised laser generated narrow beam of light displaying on the flight instrument panel (8). Peripheral visual cues would result which would alert the pilot to an unplanned departure from his desired attitude. Tests were performed in a RN Sea King, but integrating the device into a traditional flight instrument display with varying light sources and intensities and into the associated harsh vibration environment proved difficult. However using the same principle, a system of light emitting diodes placed on

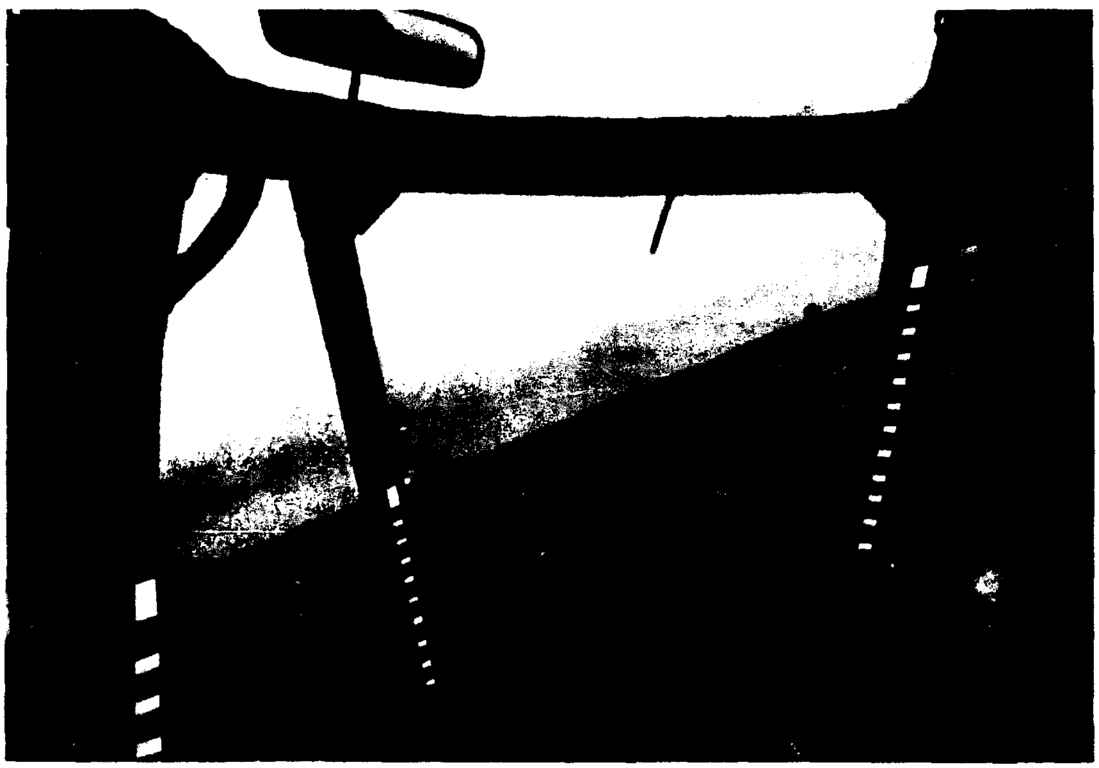

Fig 1

Pilot's View of Peripheral Vision Aid

the main cockpit windscreen frames has been developed to give similar cues (9), and is under trial at present.

To date no trial reports are available, but if successful this will be a significant step to decrease disorientation.

Height Warning Devices

However almost all RN incidents are caused by a minor departure from the planned attitude and more importantly power setting, which set up an unwanted rate of descent. Here the helicopter differs significantly from the conventional fixed wing, in that a slight reduction in power in the latter will only result in a gradual departure from the intended flight path, whereas in the former the departure will be immediate. This departure will not be picked up by a peripheral vision device, as there is no significant change in aircraft attitude.

In these instances height warning needs to be given which will alert the crew regardless of where they are devoting their visual attention. Such devices already exist in audio (aural) warnings, which are omni-directional (that is independent of the field of vision). They also have the advantage of being relatively resistant to filtering out by the brain's input processing pathways under high workload situations. Such basic devices are being fitted to RN helicopters, but they are limited in effectiveness. The reasons are:

a. They are only initiated at a preset height.
b. They are absolute warnings and give no rate or trend information.
c. Being a tone only, they require some interpretation.

What is needed therefore is a device which fulfils all these requirements. Such a project is underway at present. However to be effective great care is required in its design to ensure that unwanted and intrusive warnings do not result, and that warnings based on rates of change of height over time are correct for that particular phase of flight, as the requirements differ.

For example the accident to Sea King XZ916 occurred on climb-out from a ship on a "no horizon" night sortie when the crew were distracted by a minor problem and flew into the sea. In this instance early warning of any rate of descent is required.
Whereas in the incident quoted earlier in the paper the warning should be activated dependent on the height and rate of descent.
The outcome of trials will be reported separately.

Ditching - Underwater Egress

The measures briefly outlined should do much from a preventative viewpoint to reduce ditchings which are avoidable, or to date unavoidable. However there will always be instances where ditchings will still occur, and still occur in conditions where the helicopter will invert once on the surface of the water. A major factor in crew survivability in these eminently survivable incidents is the ability to egress successfully from the inverted aircraft. As can be seen from Reader's (4) and others' surveys straightforward egress cannot always be guaranteed. Factors influencing this are:

a. Difficulty in detaching the emergency escape windows.
b. Disorientation, for example from a deliberate though unwise early harness release.
c. Trapping or snagging from interaction with part of the airframe.
d. Overcoming the "gasp" reflex caused by submersion in cold water (10, 11, 12).

Emergency Underwater Breathing Device

The provision of a short term emergency underwater breathing device would allow the aircrew more time to overcome these problems which may occur singly or together, and such a system has been introduced by the US and Canadian Navies. A device similar to the USN's is about to enter service with the Royal Navy (13).
This is called STASS - the short term air supply system.

Fig 2

Fig 3

Because of the potential difficulties of use in untrained personnel a carefully controlled training programme is being implemented, including a shallow water training device.
Significantly, although the risk is very small, the air supply is from a pressurised source, and therefore there is potential for a cerebral arterial gas embolism in susceptible subjects, if the subject breath-holds during the short ascent. Identification of this susceptibility is difficult in practice without disbarring the subject from training. To overcome this admittedly largely theoretical impasse, a recompression chamber has been installed with clearly defined parameters for therapy, not least to avoid unnecessary hyperbaric exposure and possibly tympanic perforations in aircrew. Simplification of some aspects of the training programme is being considered, as the main objective is to familiarise the user with purging water from the system, and breathing from a pressurised source whilst not wearing a nose clip.

Other Egress Aids

Other egress aids currently under trial must be briefly mentioned for completeness. Tactile and visual aids are being introduced to offset difficulty in reaching an emergency egress point. These include:

Tactile - a shaped guide bar
Visual - an orientating pulsed light bar with the pulses directed towards the nearest egress point
- increased luminance at the egress points

These aids are discussed in more detail elsewhere (14, 15).

Conclusions

Helicopter ditchings will never be eliminated completely.
Modifications to the Sea King main rotor gearbox and provision of an emergency oil supply should reduce ditchings from mechanical failure. A peripheral vision aid and a logic voice warning for attitude and height information cues should reduce ditchings resulting from disorientation and overall ditching fatalities, and two projects have been discussed. Finally, an underwater emergency short term air supply system for the crew is being introduced which will allow more time in the event of difficutly in egress from an inverted water-filled helicopter.

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Canadian Forces Helicopter Ditchings
1952-1990

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Introduction

In 1982, Brooks and Rowe completed a 20 year retrospective review of the survival of all Canadian Military aircrew from ditching, parachuting or ejecting into both fresh and sea water, including the penetration of ice on frozen rivers and lakes. (14). For the purpose of that study, all of these mishaps were classified as water accidents. The authors originally had intended to examine all water accidents back to 1952, but due to integration of the services and the coincidental amalgamation of the RCAF Institute of Aviation Medicine and the Defence and Civil Institute of Environmental Medicine, data prior to 1962 appeared to have been lost or destroyed.

Six years later in 1986, additional information was located in the old RCAF card index from the Directorate of Flight Safety,. National Defence Headquarters. Using that *additional data*, Brooks completed a review of all types of aircraft accidents occurring in both sea water (10) and fresh water (11) for the RCAF from 1952 to 1968 and for the Canadian Forces (after integration of the three Canadian Services) from 1968 to 1987; a total period of 36 years. Moreover, it was concluded that the RCN records had been lost forever.

Since 1987, there have been just two further accidents involving helicopter ditchings, one in fresh water and one into sea water. This paper will summarise the Canadian Military experience with ditching helicopters into water over the last 38 years.

General Findings

Over the period from 1952 to 1990, there have been 17 helicopter accidents in water. Ten accidents occurred in sea water (all these have been Sea King helicopters and 7 of the accidents have occurred in fresh water (4 Kiowas, 1 Sea King, 1-H34-A Sikorsky, 1 UH-1 and 1 12-E Hiller)). There has been a total of 63 personnel involved with 15 fatalities, for an overall survival rate of 76%. The accidents are listed by helicopter type in Table 1 - sea water and Table 2 - fresh water.

Accident Sites

Crashes and planned ditching at sea have occurred wherever the Canadian destroyers have been operating i.e., off the coasts of Nova Scotia, New York City, Bermuda, the Dominican Republic and the Netherlands.

All of the fresh water accidents occurred in Canadian lakes and rivers: Dartmouth, Nova Scotia; Lake Manitoba, Manitoba; the Muskrat River and Severn River in Ontario; Findlay Lake in Quebec; Upper Arrow Lake, Nakusp, British Columbia; and the Mala River in the North West Territories. There has been no general pattern of fatalities related to any specific geographic location.

Cause of Accident

The causes of the accidents fall into 3 principle categories - mechanical, disorientation/fly-in and human error. By far, the commonest causes (52%) were mechanical problems (9 cases) *A typical example is Case 7:*

A Sea King Helicopter was approaching a ship just prior to passenger transfer in the North Sea, a banging noise was heard and a power loss was experienced. The pilot manoeuvred the helicopter clear of the ship and ditched. Following the ditching, the helicopter was water-taxied for about one minute. Emergency shut down procedures were then initiated and the rotor brake applied. Flotation bags were activated and the crew picked up by the ship's boat. Two sixth stage stator blades had failed in fatigue causing internal damage and a compressor stall followed by a loss of power in the left hand engine.

Disorientation/fly-in and pilot error shared the second commonest cause with 4 cases (23%) each. A typical example of an incident combining both disorientation and pilot error is case 13.

TABLE 1: HELICOPTER ACCIDENTS IN SEA WATER

CASE NO	AC TYPE	DATE	NO OF PERS FATAL	NON FATAL	ACCIDENT SITE	CAUSE
1	Sea King 002	1-Dec 1967	2	2	NE of Bermuda	Disorientation/Fly-in
2	Sea King 427	22-Feb 1968	0	6	W of Dominica West Indies	Mechanical Problems
3	Sea King 407	15-Jun 1968	0	4	Off New York	Engine problems, planned ditching and take-off
4	Sea King 015	24-Jun 1969	0	5	Off Bermuda	Engine problems and Human Factors
5	Sea King 420	7-Nov 1971	3	1	300 m SE Halifax, N.S.	Likely disorientation/Fly-in
6	Sea King 418	24-Oct 1973	0	4	30 m SE Halifax, N.S.	Mechanical Problems
7	Sea King 423	24-Jun 1974	0	5	Off Holland North Sea	Engine Problem
8	Sea King 439	16-Oct 1980	0	4	45 m E Halifax, N.S.	Engine problem, planned ditching and water take-off
9	Sea King 409	4-Nov 1987	0	3	20 m S Halifax, N.S.	Emergency chiplight. Planned ditching
10	Sea King 411	19-Sep 1989	0	5	260 m NW Bermuda	Main gearbox and hydraulic leak. Sank in 2000 fathoms in 1 hr 30 mins.

TABLE 2: HELICOPTER ACCIDENTS IN FRESH WATER

CASE NO	AC TYPE	DATE	NO OF PERS FATAL	NON FATAL	ACCIDENT SITE	CAUSE
11	Sea King 425	5-Jul 1983	0	4	Morris Lake N.S.	Lost control at 50 ft in hover
12	H-34A Sikorsky	30-Nov 1958	6	0	Lake Winnipeg Man.	Disorientation in snow storm during mercy flight
13	UH-12E Hiller	17-Jun 1965	0	Est 2	Muskrat River Ont	Wire Strike
14	Kiowa 244	6-Jul 1978	0	1	Mala River N.W.T.	Lost and ran out of fuel
15	Kiowa 258	13-Jun 1968	2	0	Findlay Lake Que.	Loss of control after mechanical problem/fly-in
16	Kiowa 215	18-Aug 1985	0	2	Severn River Ont	Disorientation over water in night hover/fly-in
17	Kiowa 242	7-Jul 1988	2	0	Upper Arrow Lake Nakusp, B.C. 50 km SE Revelstoke	Loss of depth perception Low flying over lake/fly-in

The pilot of a Hiller flew down the centre of the Muskrat River at a height he judged to be between 30 and 50 feet above the water at 70 knots. After the wire strike he experienced vibration, he checked the control responses, but the only significant reaction was a violent increase in vibration; he maintained the controls in an effort to maintain level flight without success. The helicopter pitched nose down in a slight turn to the right and struck the water some hundred yards beyond the wires. It rolled over to the right and ended submerged except for the left skid, and almost completely inverted. The pilot had been flying in the left seat, with both doors off and the harness in the unlock position. He was conscious of getting a mouthful of water, released his harness and got out of the left upper side, swam to a nearby boat where he was helped on board.

TABLE 3. GENERAL SURVIVAL INFORMATION

CASE NO	AC TYPE	WARNING TIME	(F) FATAL OR (NF) NON-FATAL	TIME TO RESCUE	METHOD OF RESCUE	NIGHT ACCIDENT	WATER TEMP CELSIUS
				SEA WATER			
1	Sea King	Under 15 sec	F/N F	45 min	Boat	Night	21.1
2	Sea King	Under 15 sec	N F	15-20 min	Submarine		25.9
3	Sea King	Under 15 sec	N F	Water take-off	Water take-off		?
4	Sea King	Under 15 Sec	N F	2 hr 45 min	Boat		?
5	Sea King	Under 15 Sec	F/N F	10 min	Boat	Night	21.1
6	Sea King	Under 15 sec	N F	10-15 min	Helicopter		2.2
7	Sea King	Under 15 sec	N F	5-6 min	Boat		13-15
8	Sea King	Under 15 sec	N F	Water take-off	Water take-off		12.0
9	Sea King	2-3 min	N F	20 min	Helicopter		11.0
10	Sea King	Under 2 min	N F	4 hrs	Boat		28.0
				FRESH WATER			
11	Sea King	Under 15 sec	N F	10 min	Boat		18.0
12	H-34A Sikorsky	Under 15 sec	F	?		Night	?
13	UH 12E Hiller	Under 15 sec	N F	10 min	Swam to boat		?
14	Kiowa	Under 15 sec	N F	?30 min	Waded ashore		?
15	Kiowa	Under 1 min	F	?		Night	?
16	Kiowa	Under 15 sec	N F	5-10 min	Swam/boat	Night	?
17	Kiowa	Under 15 sec	F	A/C broke up on impact			?

<u>In - flight Preparation Prior to the Knowledge of the Accident</u>

Traditionally, aircrew and passengers receive little or no warning of an impending crash. In this series of 17 cases, it is estimated that for 14 (82%) accidents, the crew were aware of the impending accident for less than 15 seconds before it occurred. The details are tabulated in Table 3 and illustrated graphically in Table 4. There were fatalities in 4 (23%) accidents in this group.

In the three remaining accidents,there was still precious little warning time, up to one minute in the fatal Kiowa accident at Findlay Lake, Quebec (Case 15); up to two minutes in the non-fatal Sea King which suffered sudden and substantial hydraulic fluid leak from the tail rotor gearbox (Case 10); and no more than three minutes in the non-fatal planned ditching of the Sea King in the Atlantic Ocean following an emergency chiplight alarm (Case 9). Case 11 is a typical example of the short warning time:

After a normal start-up, the crew of a Sea King helicopter took-off for a Water Landing Training mission. After some initial sequences had been demonstrated including a single engine take-off, the student then carried out a single engine landing and attempted a single engine take-off by himself. The take-off had to be aborted due to low rotor rpm and when rotor rpm recovered, the instructor directed the student to continue the take-off..

During this second attempt, rotor rpm again dropped before an abort could be executed, the aircraft struck the water nose down at approximately 20-25 knots ground speed. The aircraft pitched forward severing its tail pylon, and came to rest inverted in 20 feet of water. (figure 1)

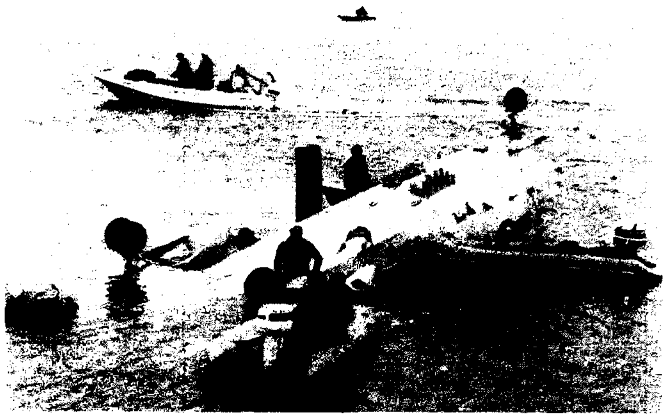

FIGURE 1
A typical accident where the helicopter sinks and is rapidly inverted

Table 5 illustrates the conditions of helicopter post-ditching in the 17 cases. One helicopter sank rapidly (Sea King-Case 6), 3 helicopters rapidly inverted (Sea King-Cases 2 and 11 and UH 12-E Hiller Case 13), 2 helicopters floated (Sea King-Case 7 and Kiowa-Case 14) and 3 helicopters sank later (Sea King Cases-4, 9 and 10). Of the remaining accidents, there were six fly-ins and two water take-offs.

Case 4 is a typical example of what happens to a helicopter during a hover at 40 feet when a mechanical problem suddenly occurs.

The pilot heard a high pitched whine from one engine. The port engine failed before the sonar dome could be fully recovered and the aircraft settled onto the water. After one minute, the pilot attempted a take-off and the aircraft rose about 10 feet before rotor rpm began to decay and the aircraft settled onto the water again. Additional water entered through the sonar well. Two further take-offs were unsuccessful. When an attempt was made to inflate the flotation bags, the starboard bag did not inflate fully and the aircraft rolled inverted. The crew was able to evacuate the aircraft and were rescued.

Night Accidents

There have been five accidents (Table 3) that occurred in darkness, two at sea, two into fresh water lakes and one into a river as follows.

(a) Two Sea Kings flew straight into the sea off Bermuda. In Case 1, all four crew might have been able to escape had the accident occurred in daylight. They were likely disoriented or distracted, as only the navigator and the observer survived. In Case 5, the crew became disorientated while carrying out a night ASW exercise off Bermuda. Because the bodies of the two pilots and the observer were not found, it is only possible to speculate what happened from the vague testimony of the surviving navigator. The two pilots, likely received fatal injuries, but could have drowned after impact. The observer also perished, possibly through injuries but maybe through drowning or a combination of both. It could be postulated that, if the accident had occurred during daylight and his injuries were not too severe, he might have been able to escape from the aircraft after impact. The accident in the cabin of the helicopter was survivable because the navigator had made a remarkable escape from approximately 20 feet submerged in 21°C sea water, perforating his ear drums in the procedure. Factors that likely contributed to his survival was that he had received Dunker training and had some diving experience.

b) An H-34A Sikorsky crew (Case 12) was on a mercy flight when the pilot became disoriented in a dense snowstorm and crashed into Lake Winnipeg near Black Island. All six occupants were killed.

c) The pilots of a Kiowa helicopter, (Case 15) lost control of their aircraft because of a

Table 4 **Warning time in 17 cases**

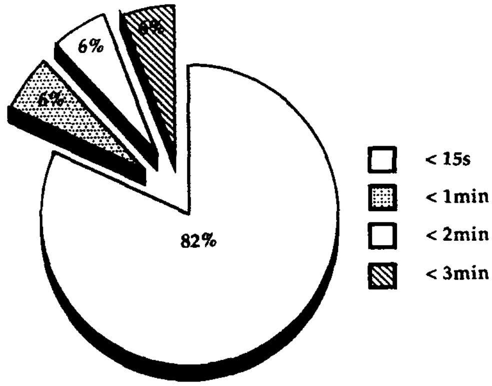

Table 5

Case No	Conditions of the helicopter post-ditching	
1	Sea King	Fly-in
2	Sea King	Rolled inverted
3	Sea King	Water Take-off
4	Sea King	Sank later
5	Sea King	Fly-in
6	Sea King	Sank immediately
7	Sea King	Floated
8	Sea King	Water take-off
9	Sea King	Sank later (1 hr 20 min.)
10	Sea King	Sank later (1hr 30 min.)
11	Sea King	Rapidly inverted
12	H-34A Sikorsky	Fly-in
13	UH 12E Hiller	Rapidly inverted
14	Kiowa	Floated
15	Kiowa	Fly-in
16	Kiowa	Fly-in
17	Kiowa	Fly-in

mechanical failure and plunged into Findlay Lake, Quebec. Both were killed instantly.

d) The pilots in another Kiowa (Case 16) attempted to conduct a night hover over water and became disorientated crashing into the Severn River in Ontario. Both crew survived, but had difficulty making an underwater escape.

Water Temperatures

Water temperatures are listed in Table 3: They have been reported in nine cases only. Eight of them were from sea water immersion by Sea King crew. The ninth was also a Sea King that ditched in a lake during a practice dipping exercise. The temperatures ranged from 0-5°C (1 case) 10-15°C, (3 cases), 15-20°C (1 case) and 20C°+ (4 cases).
Water temperatures were not recorded in the remainder of the accidents.

Method of Rescue

There has been a wide variety of rescues; eight cases by boat , two by helicopter, one rescue by a submarine and one case where a survivor waded ashore. In 5 cases, there were no survivors or there was no need to rescue anyone; i.e., the three fatal cases where the helicopter hit the water and broke up (Cases 12,15 and 17) and two cases where the helicopter was able to take off from the water and therefore, no rescue was required. (Cases 3 and 8).

Immersion Suits

Immersion suits were worn in only four of the accidents by a total of 15 personnel. All of these were Sea King accidents into the open ocean. The individual performance of each suits is illustrated as a bar chart in Table 6. There were no immersion suits worn by any of the aircrew in accidents in fresh water. This is probably due to the fact that helicopter aircrew flying over land did not expect to crash into water.

In Case 6, 30 miles southeast of Halifax in 2.2°C water where rescue took 10-15 minutes, all four of the suits leaked badly and it was questioned by the Board of Inquiry if they were of much benefit.

The suits were also worn in the Sea King accident (Case 7) off the Dutch Coast in 13-15°C water, where the crew were rescued in 5-6 minutes following the mishap. Four crew were wearing the suits which were leak tight and working according to specifications. However, one passenger did not have a suit and if the rescue time had been greater than six hours, this unprotected passenger's life would have been threatened.

They were worn by all four aircrew in the planned ditching into the Atlantic Ocean 45 miles east of Halifax (Case 8). With subsequent water take-off, they were not immersed in water and therefore not used. Lastly, they were used by the three crew in the planned ditching of the helicopter into the Atlantic Ocean 20 miles south of Halifax in 11°C water (Case 9). In this case, two of them were leak tight and one had a small/medium leak.

There were no fresh water accidents in which the wearing of an immersion suit would have made any difference to survival. In Cases, 11,13,14,15,16 and 17, the accidents occurred in the summer when the water was generally much warmer and in Cases 12,15 and 17, the accidents were unsurvivable due to the force of impact of the helicopters into the water.

Life Jackets

Life jackets were worn in 12 accidents only. They were worn in all 11 Sea King accidents; one was a mishap in fresh water, the remainder were in the open ocean. A life jacket was also worn by the pilot of the Kiowa that ran out of fuel and ditched in the Mala River (Case 14). It was found particularly useful for the rescuers who spotted it's yellow collar. A life jacket does not appear to have been worn in any of the other fresh water accidents. The reasons for this are the same as those given for immersion suits - the aircrew did not expect to crash into water when flying over land.

In only one of these accidents was it reported that there was a problem. In Case 7, the CO_2 cylinder did not work when the toggle was pulled by the crewman. Reviewing the remainder of the cases where there were fatalities (Cases 1 and 5) is difficult. Because there is not enough evidence in the Boards of Inquiry, it would be pure speculation to suggest that malfunction of a life jacket contributed to loss of life.

Life Rafts

The helicopters have carried either the single-man or the multi-place life rafts. They were available in all eleven Sea King accidents, ten of which occurred in sea water and the eleventh into fresh water (Table 7). Whether or not any of the remaining helicopters that ditched into fresh water were configured with life rafts is unknown because there were no comments made in the Boards of Inquiry. In four of the Sea King ditchings, neither type were deployed, they were not used in the two water take-offs (Cases 3 and 8), nor in a fly-in in which everything was lost (Case 5) and during the waterskid exercise when the helicopter rapidly inverted.(Case 11). In this latter case, there was a Zodiac standing by for the exercise. In the remaining accidents, there were some accidents where only the single man life raft was launched and some cases where both single and multi-place were launched as follows:

Case 1 - Two singles were inflated by the 2 survivors. The other 2 aircrew died in the fly-in. The multi-placed raft was presumed lost in the accident.

Case 2 - Five singles were inflated while the sixth one failed. The helicopter rolled over on the multi-place life raft.

Case 4 - Two singles and the multi-place raft were inflated.

Case 6 - Three singles were inflated. Through personal choice, the observer did not inflate his because he went back aft to deploy

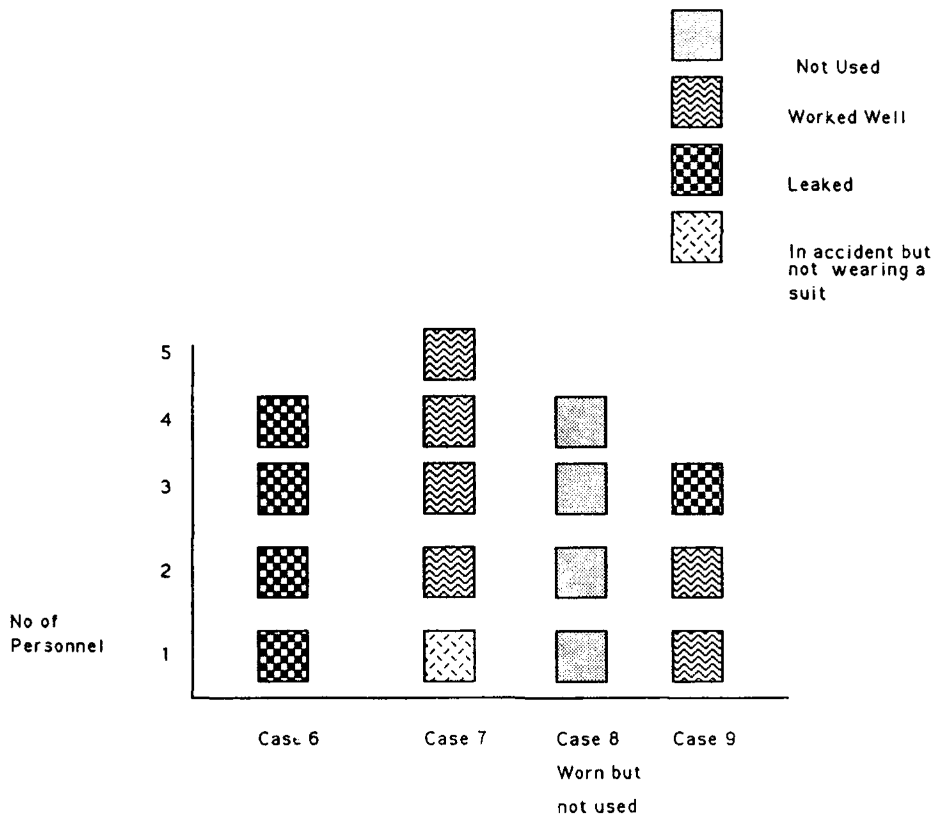

Table 6: Performance of the immersion suits which were worn in the five Sea King Accidents.

Case No.	Single-man	Multi-place
1	2 OK. 2 Lost with fatalities	Lost
2	5 OK. 1 Failed	helo rolled over on multi-place raft
3	Not used - Water take-off	
4	2 OK	OK
5	All lost in accident	
6	3 OK	Unable to launch
7	?	Launched with difficulty
8	Not used - Water Take-off	
9	Deliberately left behind	OK
10	Deliberately left behind	OK
11	Not used - Zodiac close by	

Table 7 Life Raft Performance (Sea King Helicopters only)

the multi-place life raft. When he found it impossible to release it, he made an emergency exit through the cargo door without his single-place life raft. He remained in the water close by the life rafts until rescue 10-15 minutes later.

Case 7 - Although difficult to deploy,only the 6-man life raft was inflated. The paddles were found to be missing.

Case 9 and 10 - Only the multi-place life rafts were inflated. In Case 9, the crew deliberately left their single-place rafts behind and just used the six man raft. The reason given was that the rescue helicopter was virtually alongside waiting to hoist them up soon after the accident.

The longest time spent in a raft was 4 hours and several crew became sick. In this case, anti-motion sickness tablets were labelled with a generic chemical name (which incidentally washed off after the bottle got wet). The aircrew were unsure whether the tablets were to be used for sea sickness! There was only one other accident where motion sickness was reported.

Water Survival Training

There were five accidents in which there were very positive comments by survivors which illustrate the necessity and usefulness of water survival training: "wet dinghy drill extremely useful", "ten years of sea survival training paid off", "sea survival training made ejection and water survival easier", "good briefings on survival and escape drills helped", and "Dilbert Dunker and wet dinghy drills excellent in alleviating anxiety and stress of survival". The benefit of diving experience has also been well demonstrated by a Sea King navigator, who was able to make a conscious underwater escape from a severely damaged cabin, whereas three other crew members perished (Case 5).

Discussion

From 1952-1990, there has been an overall survival rate of 76%. These figures compare well with the U.S. Navy and British experience. The U.S. Navy (12,13,15,16,20) reported an overall cumulative rate from 1982 to 1986 of 74% during day time and 65% during night time flying. From 1972 to 1988, the British Military Services (7, 18, 25, 26) reported 94 accidents involving 342 personnel for a survival rate of 84%. Our rates are slightly better than the civilian experiences. Ferguson (12,13) reported on a large series of 28 civilian helicopter accidents in the North Sea. There were 344 personnel involved with 130 fatalities for a survival rate of 62%.

Mechanical problems have caused fifty two percent of the accidents. These figures agree with the British military figures (94 accidents) where 46 accidents were caused by mechanical failure, these were made up of engine failure (31 cases), transmission failure (8 cases) and tail rotor failure (7 cases). This also agrees with the observations made by the British Airworthiness Board in 1984 (19). They concluded that the percentage of accidents that are due to airworthiness causes is greater for helicopters than for fixed wing.

When helicopters ditch in water, the event is sudden and there is precious little time to prepare for the catastrophe. This study confirms that in over eighty percent of cases, the aircrew had less than 15 seconds warning. The only other direct reference to warning times in the literature is by Anton(6). He reviewed seven U.K. registered helicopter accidents in the North Sea: There was less than one minutes warning time in two of them and less than five minutes in two of the others.

The short warning time is why the importance of a good pre-flight briefing is paramount. It prepares the occupants for the sudden immersion event and should include a short description of personal and aircraft safety equipment and it's use. Examples include the requirement for the immersion suit to be done up before ditching, so that it will be waterproof; the technique to activate the life preserver; the method of deploying the life raft;, and the operation of the headset/helmet. The problems of underwater escape should be described, especially to the passengers who have not had a survival course. In particular the fact that water will rush in very rapidly, it will be cold and dark and that disorientation will occur. Survival techniques should be explained, such as adopting a good crash position and not undoing the harness until all motion has stopped. Emergency exits and methods for normal and emergency egress should be discussed to give some indication of how much force is required to operate emergency release handles, pushout windows open emergency doors.

Helicopters do not float well. Only 13% floated, 26% sank or rapidly inverted and 20% sank later. The results from this smaller series are a little better than the experiences of other operators . Reader (18) reported on 94 ditchings in the British military series: 50% of the helicopters immediately inverted and 27% inverted after a delay. Ferguson's (12,13) series of 28 civilian helicopters operating in the North Sea, only 14 helicopters (50%) floated, of which two barely floated, one floated inverted, one capsized "quickly", one capsized after an hour, two sank "eventually" (after some hours), and two sank during salvage operations. In the other 14 accidents, ten helicopters (37%) sank rapidly, one sank inverted and three sank with the fuselage broken into pieces. In two cases, the helicopter broke up in midair before hitting the sea and sinking. In two cases the condition of the helicopter at the time of impact with the sea could not be established.

Difficulty with deployment of the multi-placed life raft, has been reported by Anton (6) and Reader (18). This difficulty was confirmed in this series too. There was one case where it could not be launched, one case where the helicopter rolled over on top of it and another case where it was only launched after a lot of difficulty. Bohemier (9) has recently conducted a study using 27 naive subjects in the Survival Systems helicopter underwater escape trainer configured to the tail section of the Sikorski S-61 (figure 2) to investigate the ability to deploy a multi-place

Figure 2

A typical helicopter underwater escape trainer (HUET) courtesy Mr. Bohemier, Survival Systems, Dartmouth, Nova Scotia.

life raft in a rapidly sinking helicopter. He concluded that even with good regular training and refresher training, the possibility of success is between 50 and 74% The solution to the problem is to mount the life rafts external to the fuselage as in the Bell 214.

The old MK II Buaer life jacket was introduced into the U.S. Navy in 1946 (2) and is still being used by the Canadian Sea King aircrew. It is now outdated and soon will be replaced by the new Mustang life jacket.

The performance of the immersion suit has been disappointing. Considering the thousands of hours that the aircrew have put up with the discomfort of the immersion suit, only to find that it worked satisfactorily in six personnel, and was of very marginal benefits in five personnel reveals that it is time to review the philosophy of immersion protection for Canadian military helicopter aircrew.

It was also observed that the survival rate was improved if the aircrew had experienced training in a helicopter underwater escape trainer or had been (for instance) a ship or sports diver. As a result, all aircrew in the Canadian Forces must now undergo formal practical underwater escape training and this new programme is working well, although there have been no accidents to evaluate its effect since its instigation.

The other two problems for making a successful underwater escape are an ability to breath-hold in cold water and the ability to overcome disorientation/poor vision. This is vividly described by Gill (9) after his first escape from an underwater trainer.

"DITCHING"

As the HUET drops, I can see the water surge upwards through the deck and I take a deep breath. Two things immediately happen as the turbulence engulfs me; a nose full of water and a loss of any visible reference points.

As the fuselage inverts I find myself upside down. Sitting upright is a contradiction. They should have told me to sit downright, to force my body against the buoyancy that is pulling me to the floor of the HUET.

Nothing makes sense anymore, except the urge to exhale and breathe. Stabs of light are coming from all different directions. Nothing is where it should be. I don't know how much longer I can hold my breath. I don't think I can get out. I can't see the exit.

Finally, I get my seat belt released and immediately I begin to float. If only I could get upright things might improve.

As I float upwards, my legs flailing, I realise I am getting tangled in the seats (which for some strange reason are now located on the ceiling of the cabin). I claw my way downwards, against the buoyancy, to find an exit. Any exit.

The aisle. If I can make the aisle I can forget the right exit and get out through the big opening in the rear of the HUET. The aisle is not there, neither is the exit.

Wait...what's that patch of light?

The first problem is not new and was originally addressed in 1945 (1) by providing aircrew with an A-13 mask, A-14 oxygen regulator and USN walk-around assembly. In the last 15 years, various compressed air supplies have been examined (12,13,17,21,22,23) and are now in service with the U.S. Navy,. the Italian Navy and the Canadian Sea King Squadrons The U.S. Coast Guard developed a unique life jacket that contains its own supply of oxygen which is also in service. The U.S. Navy HEEDS system has already proved its worth, yet all of these systems are an interim solution and work continues to find improvements.

The visibility problem has been admirably investigated by Allan (3,4,5). The addition of a simple illuminated bar that strobes quicker as the survivor approaches the escape hatch is an excellent simple solution, but to date has not been implemented in any Canadian helicopter and may not be implemented in the new EH 101 which is proposed as a replacement for the aging Sea King fleet.

Conclusions

From 1952-1990, a period of 38 years there have been 17 helicopter accidents. Ten of these have been in sea water, 7 in fresh water.

There has been no apparent correlation between geographic location and either incidence of accidents or number of fatalities.

The Sea King helicopter showed the highest incidence of water ditching with 11 cases (66%), 10 in sea water, 1 in fresh water.

The Kiowas show the next highest incidence of a water ditching with 4 cases (24%).

The overall survival rate was 76% which is similar to that experienced by other operators of military and civilian helicopters.

Mechanical problems caused over fifty percent of the accidents, followed by disorientation and pilot error, each of which caused 23% of the remainder of the accidents.

There have been 5 accidents at night and in two cases darkness contributed to the fatalities.

The warning time in all cases has been less than three minutes and in 14 cases (82%) under 15 seconds.

The helicopter floats poorly in water and like other operators, the experience of the Canadian Forces has been very similar, only 13% floated, while 26% sank or rapidly inverted and 20% sank later.

Also like other operators, in a rapidly sinking helicopter, there has been serious difficulty experienced in deploying the multi-placed life raft.

Considering that primary life support equipment, such as life jackets and life rafts should work perfectly, there have been a number of failures.

Rescue in helicopter ditchings in water has been very quick, the longest time spent in a life raft was 4 hours.

Survival training, underwater escape training and experience as a diver all contributed to survival.

The immersion suits, an unpopular garment with aircrew has not performed well and the whole philosophy of immersion protection requires review.

Acknowledgement

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ACCIDENTS D'HELICOPTERE AU DESSUS DE L'EAU DANS LA MARINE NATIONALE

Etude épidémiologique sur la période 1980-1991

par

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ABSTRACT
Helicopter ditching in the French Navy in years 1980-1991. By P. Giry, P. Courcoux & J.P. Taillemite.

During the years 1980-1991, 11 French Navy helicopters ditched in the sea : 3 Super-Frelon, 3 LYNX-WG13 3 Alouette III and 2 Alouette II, 10 of them being equipped with flottability devices. Structure default was the identified cause of the accident in 2 cases, engine failure in 5 accidents, human error in 5 issues, the last one being unknown. Three accidents occured at night, the 8 others during day-time. 54 persons (34 crew, 20 passengers) have been involved. The outcome has been : 19 dead or disappeared, 4 wounded and 31 uninjured.

The aircraft capzised in 8 out of 11 occurences, almost immediately after ditching in 6 cases, after a delay long enough for all the crew to escape in 2 cases. In one of these last occurences, all the crew but 1 survivor (13 people) died (probably from cold exposure). In the other one (ditching in shallow warm waters, close to shore) no casualty occured (10 safe). Escape problems have been reported in 2 accidents (5 people involved), leading to 3 casualties and 1 injured. Localization of survivors has been a major problem in 1 accident (visibility was so poor that only sound signals could be efficient).

Data are analyzed and compared to available information.

Les accidents d'hélicoptères au dessus de l'eau sont relativement fréquents, surtout depuis le développement de l'hélitransport vers les plate-formes pétrolières de la Mer du Nord. Dans sa revue de 1991, Brooks signale l'absence de données en provenance de la Marine Nationale. Le but du présent travail est de colliger les accidents survenus dans l'Aéronautique Navale Française entre le 1er Janvier 1980 et le 31 Août 1991 pour en analyser les données et les confronter avec celles de la littérature.

Cette étude ne répertorie pas les autres accidents survenus dans la Marine Nationale, mais dans des conditions différentes (autres types d'aéronefs, accidents sans amerrissage, etc...).

ANALYSE DES ACCIDENTS

Dans la Marine Nationale, le Conseil Permanent de la Sécurité Aérienne de la Marine (CPSA/MAR) réunit l'ensemble des informations concernant les accidents d'aéronefs. Sur notre demande, il a répertorié les accidents d'hélicoptère survenus au dessus de l'eau pendant la période s'étendant du 1er Janvier 1980 au 31 Août 1991; ils ont concerné 11 appareils et 54 personnes

ANALYSE GENERALE

Pour faciliter la compréhension, le tableau I donne la liste des accidents et leur principales caractéristiques. Dans la suite de cet exposé, tués (corps retrouvés) et disparus (corps non retrouvés) seront confondus

Tableau I : accidents d'hélicoptère au dessus de l'eau survenus dans la Marine Nationale (période du 1er Janvier 1980 au 30 Août 1991)

Accident	Appareil	Personnels PN	Personnels Pax	Issue Tués	Issue Blessés	Issue Indemne
A	SUPER-FRELON	4	0	3	1	
B	SUPER-FRELON	6	8	13	1	0
C	SUPER-FRELON	4	6			10
D	LYNX-WG13	3	1			4
E	LYNX-WG13	3	0	3		
F	LYNX-WG13	2			1	1
G	ALOUETTE III	2				2
H	ALOUETTE III	4			1	3
I	ALOUETTE III	2	2			4
J	ALOUETTE II	2	1			3
K	ALOUETTE II	2	2			4
Total		34	20	19	4	31

Il s'agit d'appareils, soit conçus pour l'Aéronautique Navale (SUPER-FRELON, LYNX-WG13) soit navalisés (ALOUETTE II et III). A l'exception d'une des Alouette II, tous ont une flottabilité positive assurée par construction (coque du SUPER-FRELON), adjonction de volumes de flottabilité (boudins latéraux gonflables sur ALOUETTE II et III) ou de retardateurs d'immersion (ballons de roues sur LYNX-WG13).

FREQUENCE (tableau II)

Tableau II : répartition de la fréquence des accidents

Année	80	81	82	83	84	85	86	87	88	89	90	91
Nombre	3	0	1	2	0	1	1	1	0	2	0	0

La fréquence moyenne des accidents est de 1/an. Ils concernent en moyenne 5 personnes par an (3 membres d'équipage et 2 passagers).

CAUSES (tableau III)

Tableau III : Causes des accidents répertoriés

Cause		Nombre	Cas
Technique	Avarie de structure	2	A+C
	Avarie moteur	5	B+D+G+I+K
Humaine		3	J+F+H
Inconnue		1	E

Les accidents ayant une pour origine une défaillance mécanique sont les plus fréquents (64%). Dans ce groupe, les pannes mécaniques non liées à la structure sont la cause la plus souvent identifiée (70% des avaries mécaniques). Dans les deux cas où la cause de l'accident est un défaut de structure, il s'agit d'un défaut sur une pale du rotor principal d'un SUPER-FRELON.

L'erreur humaine n'est à l'origine que de 27% des amerrissages.

TYPES D'AERONEF (tableau IV)

Tableau IV : Répartition par type d'appareil des accidents d'hélicoptère survenus dans la Marine Nationale entre 1980 et 1991

Type d'aéronef	Nombre d'accidents	Nombre de personnes Equipage	Nombre de personnes Passagers
SUPER-FRELON	3	14	14
LYNX-WG13	3	8	1
ALOUETTE III	3	8	2
ALOUETTE II	2	4	3
Total	11	34	20

La répartition des accidents par type d'appareil ne permet pas de mettre en évidence un fréquence particulière sur un type (3 SUPER-FRELON, 3 LYNX-WG13, 3 ALOUETTE III et 2 ALOUETTE II). Il ne nous a pas été possible de rapporter ces chiffres au nombre d'aéronefs en service ou au nombre d'heures de vol par type d'hélicoptère.

CONSEQUENCES (tableau V)

Tableau V : Conséquences des accidents au plan humain

Issue	Equipage Nb	Equipage %	Passagers Nb	Passagers %	Total Nb	Total %
Tués	11	20			11	20
Disparus	1	2	7	13	8	15
Blessés graves	1	2			1	2
Blessés légers	2	4	1	2	3	6
Indemnes	19	35	12	22	31	57
Total	34	63	20	37	54	100

Ceci représente en moyenne par an : 1,7 mort ou disparu, 0,36 blessé, 2,8 indemnes. La proportion globale de survivants est de 65%.

CAUSES DES DECES

Sur les 18 cas où la cause du décès est identifiée avec certitude ou hautement probable : 13 sont dus au froid par immersion dans de l'eau à 10°C (B), 5 sont probablement dus à la "brutalité" de l'impact avec la surface de la mer (A et E); il est impossible d'affirmer que c'est le choc qui a été mortel mais ce point de vue semble le plus probable.

CIRCONSTANCES
Trois accidents ont eu lieu de nuit (27%). Pour l'un d'entre eux (E), il n'y a eu aucun rescapé. Pour les 2 autres (C & F), il n'y a pas eu de victime. Il n'est pas possible d'analyser au plan statistique la différence jour/nuit.

DUREE DE MAINTIEN SUR L'EAU
A l'exception des 3 accidents impliquant des Alouette III (27% du total), tous les appareils ont sombré (73%).

Après amerrissage, l'appareil coule immédiatement dans 4 cas (36%). La durée de maintien à flot est "brève" dans 2 cas (18%), chiffrée à environ 40 minutes dans 1 cas (cas B), et suffisamment longue pour permettre un ensemble de manoeuvres de sauvetage, tant de l'équipage que de l'appareil dans les 4 autres cas (36%).

CONDITIONS DE L'EVACUATION
Dans 9/11 accidents, quand l'impact ne fut pas trop violent, ou/et quand le témoignage des rescapés est disponible, les conditions d'évacuation ont pu être analysées. Elles sont rapportées au nombre de sujets concernés dans le tableau VI.

Tableau VI : Conditions de l'évacuation de l'appareil (Nombre de personnes concernées; * évacuations hors eau ou à faible immersion selon les personnes)

Avant immersion		Sous l'eau		Impossible		Non rapporté	
Nb	%	Nb	%	Nb	%	Nb	%
37	69	11	20	3	6	3	6
B,C,D,G,H,I,K*		A,F,J,D*,K*		A*		E	

L'évacuation a pu se faire avant que l'appareil ne s'enfonce pour 37 personnes (19 membres d'équipage et 18 passagers , 69% des personnes transportées). Elle s'est faite sous l'eau pour 11 personnes (9 membres d'équipage, 2 passagers soit 20% des personnes transportées). Elle a été considérée comme impossible pour 3 personnes (tous membres d'équipage, 6% des personnes transportées).

Il est rapporté des difficultés d'évacuation pour 7 personnes au cours des accidents A et F (3 pilotes, 1 copilote et 3 passagers, 18% des personnes évacuées).

Dans les accidents D et K, la situation a été mixte : le temps d'enfoncement a été rapide; une partie des personnels a pu évacuer hors eau, alors que le reste de l'équipage a dû évacuer après immersion partielle de l'appareil.

LOCALISATION DES SURVIVANTS
La localisation du site de l'accident a été connue dans tous les cas. Celle des naufragés n'a pas posé de problème majeur dans 10 cas. En revanche, pour le 11ème (B), bien que le site de l'accident ait été parfaitement con-nu, et que des moyens de repérage tant aériens que de surface aient été proches, la visibilité sur zone était tellement mauvaise que le repérage des survivant a posé des problèmes insurmontables.

ACCIDENT PARTICULIER
Le cas B mérite une description et un commentaire. Un SUPER-FRELON transite en hiver entre le continent et la Corse. A son bord se trouvent 3 membres d'équipage et un groupe de 11 Commandos Marine. D'après les informations recueillies, aucun d'entre eux ne porte de combinaison étanche (elle n'était pas obligatoire pour les aéronefs multi-moteurs à cette époque). Traversant un grain de neige, (température de l'air ≤0°C), 2 des 3 turbines sont étouffées. L'équipage pose l'appareil sur l'eau (creux de 2-3 mètres, TH2O<10°C, visibilité quasiment nulle). Celui-ci reste "à plat" un temps suffisant pour que l'évacuation complète se fasse en bon ordre (durée avant disparition complète de l'avion >40 minutes). Avant l'évacuation complète, un des passagers extrait de l'appareil un "colis orange" non arrimé qu'il pense être le matériel de sauvetage; ce dernier coule immédiatement. Tous les occupants se retrouvent à l'extérieur, brassière de sauvetage gonflée. L'hélicoptère "cabane" alors (mais reste à flot, inversé), et il n'est plus possible de rentrer à l'intérieur pour récupérer le matériel de survie (et en particulier le radeau de sauvetage). Un BREGUET ALIZE survole le lieu du naufrage environ 40 minutes après l'accident. L'équipage aperçoit la queue de l'appareil et 2 naufragés. Il ne voit pas les autres qui sont répartis en 2 groupes, respectivement à 30 et 100 mètres de l'épave. Plus tard, un BREGUET ATLANTIC survole la zone, et ne voit ni les naufragés, ni les fusées de détresse tirées lors de son passage. A la tombée de la nuit (environ 5 heures après l'accident), il reste 2 survivants. Les recherches sont poursuivies de nuit par des bâtiments de surface. L'un des naufragés voit passer à proximité un remorqueur. Il crie ; le bateau le repêche. Il sera le seul survivant (après environ 7 heures d'immersion). Les recherches sont poursuivies et retrouvent 7 corps inertes.

DISCUSSION
Cette série est limitée. Toutefois, l'analyse statistique a été tentée.

INCIDENCE ET CONSEQUENCES DES ACCIDENTS
Les accidents d'hélicoptère au dessus de l'eau sont peu nombreux dans la Marine Nationale (1 par an en moyenne).

Dans notre statistique, aucun type d'appareil n'a plus d'accidents que les autres. Cependant, il faut noter que le parc de LYNX-WG13 est plus important que celui des autres appareils, et que leur principale mission étant la lutte anti-sous-marine (en particulier à bord des frégates), leur activité leur impose de longs séjours en vol stationnaire au dessus de l'eau. En revanche, les SUPER-FRELON sont relativement anciens, et leurs missions comportent de longues durées de survol maritime (liaisons, missions SAR, etc...). Il eut été intéressant de rapporter le nombre d'accidents au nombre d'heures de survol maritime par type d'appareil. Les données ne sont pas disponibles avec une précision suffisante pour permettre un calcul valable.

Nous avons comparé nos statistiques avec celles disponibles concernant l'ensemble des accidents d'hélicoptères militaires en nous basant sur les données rapportées par Brooks (tableau VII).

Tableau VII : comparaisons des statistiques pour l'ensemble des appareils

	Marine Nationale	Autres Marines
Morts	19	247
Survivants	35	799
Mortalité	35 ± 7%	24 ± 1%
c^2 = 9,55 P < 0,01		

La proportion de survivants est plus faible dans la Marine Nationale (65 ± 7%) que dans l'ensemble des Marines militaires (76,4 ± 1,3%). Il semble que cette disproportion soit principalement due à l'importance relative de l'accident B (1 accident sur 11 représente 68% des morts). Si cet accident n'est pas pris en compte, la proportion de survivants dans notre statistique devient 85 ± 6% ; elle est alors plus faible que pour l'ensemble des Marines militaires (c^2 = 4,26, P<0,05).

L'analyse a été faite en fonction du tonnage des appareils : "moyen" (SUPER-FRELON, SEA-KING, SEA-KNIGHT), "faible" (LYNX et taille inférieure) : tableaux VIIIa et b.

APPAREILS DE "MOYEN" TONNAGE : Pour la Marine Nationale, seuls les 3 SUPER-FRELON (A, B, C) sont concernés.

Tableau VIIIa: comparaisons des statistiques pour les hélicoptères militaires de moyen tonnage

	Marine Nationale	Autres Marines
Morts	16	68
Survivants	12	307
Mortalité	57%	22%
c^2 = 49,9 P < 0,01		

Notre proportion de survivants (43 ± 9%) est plus faible que pour les autres Marines (82 ± 2,0%). Il est probable que cette différence tient à l'accident B dans lequel il n'y a eu qu'un survivant (13 morts sur un total de 16 dans notre série). Pour l'accident A, la proportion de décès est également très élevée (3/4).

En revanche, pour l'accident C, aucune perte n'a été déplorée (0/10).

APPAREILS DE "FAIBLE" TONNAGE : Pour confirmer ce point, la même analyse a été faite pour les appareils de faible tonnage (capacité d'emport inférieure ou égale à celle du LYNX-WG13).

Tableau VIIIb : comparaisons des statistiques pour les hélicoptères militaires de faible tonnage

	Marine Nationale	Autres Marines
Morts	3	27
Survivants	23	51
Mortalité	12%	36%
c^2 = 5,1 P < 0,01		

En ce qui concerne les appareils de faible tonnage, le taux de survie que nous observons (88 ± 2%) est significativement supérieur à celui des autres Marines (65,4 ± 3,4%). Le taux moyen de survie est de 71,2 ± 4,4%).

Il est donc très probable que notre taux de survie global plus faible soit lié au poids de l'accident B (qui n'intervient pas dans la statistique des hélicoptères de petite dimension). En revanche, le taux de survie plus élevé que nous observons avec les appareils de faible tonnage tient très probablement aux accidents d'ALOUETTE, pour lesquels tous les personnels ont survécu.

PROPORTION ET CAUSES DES DECES : Dans son analyse statistique, Brooks indique une proportion de morts comprise entre 20 et 45% selon les séries. Dans la notre, la proportion de morts (corps retrouvé), est de 28%, ce qui serait dans la moyenne de Brooks. Mais si le regroupement morts+disparus (corps non retrouvés rapidement), la proportion monte à 49%, ce qui est à la limite supérieure indiquée par cet auteur.

Les causes de la mort se répartissent en 3 catégories : au moment de l'impact, impossibilité d'évacuer l'aéronef, liée aux conditions de survie. Il est difficile de faire la différence entre les deux premières catégories, surtout quand les corps ne sont pas retrouvés. Dans notre étude, elles se répartissent comme suit :

impact ou évacuation	6 (A, E)	32%
survie (hypothermie)	13 (B)	68%

La cause qui a fait le plus de victimes dans notre statistique est certainement l'hypothermie (72% du total des morts ou disparus, dans 1 seul accident). Il s'agit des 13 personnes concernées par l'accident B. L'abaque de Molnar (sujets tout venant) prévoit un temps de survie dans de l'eau à 10°C compris entre 1 heure (pas de mort) et 3,5 heures (100% de morts). Celle de Boutelier pour les mêmes conditions indiquent un temps d'atteinte de Trectale=35°C compris entre 5,2 et 4,5 heures en fonction de la vitesse du vent (sujet nu à panicule adipeux de 20 mm). Saunders, pour les conditions citées, estime un temps de survie de 6 heures. Le seul rescapé a été recueilli après 7 heures d'immersion. Ce temps est nettement supérieur à celui prévu par Molnar et Boutelier, mais dans l'ordre de grandeur prédit par Saunders. Le temps de survie de ce naufragé vient peut-être du fait qu'il était rompu aux situations stressantes et de survie (commando Marine), et était en pleine possession de ses moyens physiques. Dans cet accident, un certain nombre de facteurs aggravants sont venus compliquer la situation : absence de port de la combinaison étanche pour l'équipage, et donc défaut de protection thermique ; impossibilité de récupération des matériels de survie (radeau de sauvetage) et donc de se soustraire à l'immersion.

Nous n'avons pas la notion de prise position de protection thermique (Help cu Huddle) dont l'efficacité a été prouvée (Collis et al). L'état de la mer a provoqué la dispersion des naufragés, ce qui a empêché leur repérage. Tous les naufragés se sont retrouvés en surface, brassière gonflée au moment du retournement de l'appareil, et la noyade semble donc peu probable. La mort par hypothermie est hautement probable dans cet accident.

En ce qui concerne les autres causes de décès, elles sont le plus souvent accidentelles, liées au condition de l'impact. Dans le cas E (3 morts), l'examen des corps retrouvés dans l'épave a montré que la cause de la mort était la gravité des blessures au moment de l'impact.

Dans l'accident A (3 morts, 1 blessé), le rapport fait état de l'impossibilité d'évacuer, sans autre détail. Il n'est donc pas possible d'établir de conclusions fermes sur cet accident.

ANALYSE DES ACCIDENTS

Vitesse et conditions d'amerrisage : l'amerrissage s'est produit à grande vitesse pour les accidents A, E, J causant 6 morts et 4 blessés (60% de morts). Cette mortalité est nettement supérieure à la moyenne générale. Quand l'amerrissage a eu lieu à faible vitesse, il n'y a pas eu de mort du fait de l'impact.

Retournement : Aucune des ALOUETTE III ne s'est retournée. Il semble que leur dispositif de flottabilité soit particulièrement efficace. Dans tous les autres cas, l'appareil s'est retourné avant de couler. Pour 2 d'entre eux, le retournement a été très tardif (B, C). Les conséquences du retournement peuvent être directes (difficulté d'évacuation de l'appareil; (F, G), ou indirectes (dans le cas B, il a rendu impossible le dégagement des équipements de survie ; cause de la mort de 13 personnes).

A partir des informations disponibles, l'évacuation ne semble pas avoir posé de problème particulier à nos équipages.

Durée de maintien à flot : La durée de maintien à flot est très variable. Elle semble plus liée aux conditions de l'accident ou au type d'appareil qu'aux conditions météorologiques. Quand l'appareil peut se poser de façon relativement douce, elle est suffisamment longue pour permettre une évacuation (B, C). Lors des impacts brutaux, il n'a pas été décrit de temps de flottaison significatif (A, E, J).

Rôle le forme de la cellule : les deux accidents dans lesquels le temps de maintien à flot a été le plus long concernaient les SUPER-FRELON, dont la flottabilité est intrinsèque : la partie inférieure de cellule est en forme de carène.

Rôle des flottabilités additionnelles : le dispositif équipant les Alouette III (G, H, I) semble particulièrement efficace : il a permis la récupération des 3 appareils de ce type accidentés, sans aucun blessé ni mort. Toutefois, ce type de flottabilité ne peut être appliqué qu'à des appareils très légers (le volume nécessaire serait disproportionné pour des appareils de fort tonnage).

Rôle des retardateurs d'immersion : le rôle des retardateurs d'immersion mis en place sur les LYNX-WG13 n'est pas de maintenir l'appareil à flot en position normale, mais de limiter la vitesse d'enfoncement. Dans l'accident D, ils ont maintenu l'appareil retourné en surface, limitant la profondeur à laquelle l'équipage a dû évacuer (2 mètres environ). Dans le cas F, il ont été inefficaces, l'appareil ayant coulé immédiatement.

EVACUATION : L'évacuation n'a posé de problème que dans un nombre réduit d'accidents (F, G). Le tableau IX résume les cas où les personnels ont eu à évacuer l'appareil.

Tableau IX : situations d'évacuation des survivants

	Sous l'eau	En surface	Total
Equipage	8	20	28
Passagers	2	16	18
Proportion	24%	86%	100%

En ce qui concerne les équipages, la proportion d'évacuations sous l'eau (29 ± 9%) et hors eau (71 ± 12%) sont significativement différentes. Ce point est probablement dû à l'importance relative des accidents d'ALOUETTE III, pour lesquelles il y a moins de passagers que dans les autres appareils. Pour tenter de déterminer si le type d'appareil influe sur les conditions d'évacuation, nous les avons comparé pour les seuls équipages de notre statistique.

Tableau X : répartition des types d'évacuation de l'équipage en fonction du type d'appareil

Appareil	Sous l'eau	En surface
SUPER-FRELON	0	11
LYNX-WG13	5	0
ALOUETTE III	0	10
ALOUETTE II	5	2

Il n'y eu d'évacuation sous l'eau ni avec les SUPER-FRELON, ni avec les ALOUETTE III. Il n'y a pas eu d'évacuation en surface avec les LYNX-WG13. Il semble donc que le type d'appareil influence les circonstances de l'évacuation. L'évacuation subaquatique semble être la règle avec les LYNX-WG13.

En reprenant l'ensemble des informations disponibles ayant concerné des LYNX-WG13 (France + Pays Bas + UK + Danemark), on retrouve 8 accidents. Sur 6 cas, 17 personnes ont été impliquées. En se référant uniquement aux Personnels Navigants, 13 membres d'équipages ont été concernés, et il y a eu 7 survivants (54%). Nos données font état de 8 PN concernés avec 5 survivants (63%). Ces chiffres sont tout à fait comparables.

Reprenant toutes les données de Brooks (civils et militaires), nous avons tenté de déterminer s'il y a une relation entre le taux de survie et la taille de l'appareil. Pour ne pas compliquer l'analyse, seuls ont été retenus les membres d'équipage (qui ont probablement tous effectué un entrainement à l'évacuation), éliminant systématiquement les accidents dans lesquels il y a surement des passagers non entraînés, ou dans lesquels la distinction n'est pas possible (tableau XI).

Tableau XI : Comparaison de la mortalité en fonction de la taille des appareils (personnels concernés)

Tonnage	Moyen	Faible
Morts	188	37
Survivants	380	72
Mortalité	33 ± 2%	34 ± 5%
c^2 = 0,01, P > 0,90		

La taille du porteur n'influence pas la probabilité de survie (toutes sources confondues).

<u>Rôle de l'entraînement</u> : D'après nos chiffres, chaque fois que l'évacuation d'un équipage a été tentée (sujets non gravement blessés), elle a réussi. Un seul passager a dû évacuer l'appareil sous l'eau (cas G). Il a été aidé par le copilote de l'appareil. Dans tous les autres cas de transport de passagers, l'évacuation a pu se faire hors eau (SUPER-FRELON). Il n'est donc pas possible d'affirmer, à la seule lumière de ces informations, si les passagers (non soumis à l'entrainement de l'Ecole de Survie et de Sauvetage de l'Aéronautique Navale, ESSAN) courent des risques plus importants que les sujets entrainés. Nous avons tenté l'analyse en reprenant l'ensemble des données fournies par Brooks (civils et militaires).

Tableau XII : Comparaison de la mortalité entre accidents militaires (tous confondus) et accidents civils en Mer du Nord

	Militaires	Civils
Morts	247	129
Survivants	799	216
Mortalité	24 ± 1%	37 ± 3%
c^2 = 24,9 P < 0,01		

L'analyse statistique montre que la proportion de morts est plus importante dans les accidents civils de Mer du Nord (37,4 ± 2,6%, Moyenne ± SD) que pour les accidents militaires (23,6 ± 1,3%). Il est possible que cette différence soit due au taux élevé de passagers non entraînés dans les accidents civils. Nous avons donc séparé, pour l'étude des accidents civils, ceux avec plus de 5 personnes à bord (forte proportion de passagers) de ceux pour lesquels il y avait 5 personnes ou moins à bord (forte proportion d'équipage, tableau XIII).

Tableau XIII : Comparaison de la mortalité entre accidents civils avec plus de 5 personnes à bord et ceux avec 5 ou moins

	Civils < 5	Civils > 5
Morts	5	124
Survivants	29	187
Mortalité	15 ± 6%	40 ± 1%
c^2 = 8,29 P < 0,01		

L'examen du tableau XIII montre que la mortalité est plus élevée dans les transports à forte proportion de passagers (>5 personnes à bord, 39,9 ± 2,1%) que si le nombre de passagers est faible (≤ 5 personnes à bord, 14,7 ± 6,3%).

Dans les transports à faible proportion de passagers, il est probable que la proportion d'équipages qui ont subi un entraînement spécifique est plus grande. Pour éclaircir ce point, nous avons comparé les accidents civils "à forte proportion d'équipage" aux accidents militaires (tableau XIV).

Tableau XIV : Comparaison de la mortalité entre accidents militaires (tous confondus) et accidents civils avec 5 personnes ou moins à bord

	Militaires	Civils < 5
Morts	247	5
Survivants	799	29
Mortalité	24 ± 1%	15 ± 6%
c^2 = 1,46 P < 0,20		

L'examen du tableau montre que la différence n'est pas significative : le taux de survie des équipages militaires (76,4 ± 1,3%) n'est pas différent de celui des accidents civils à forte proportion d'équipage (85,3 ± 6,1%). Cette répartition peut provenir de 2 causes : dans les transports civils, les aéronefs sont différents entre vols à faible ou forte proportion de passager (avec en particulier de nombreux hélicoptères de technologie ancienne en milieu civil) ; les équipages d'hélicoptère, civils ou militaires, ont en général été soumis à un entraînement à l'évacuation, ce qui n'est pas possible pour les passagers.

Il est probable que la différence entre les taux de survie des passagers et des équipages vient de cette dernière différence. Quand cette séparation équipage/passagers est appliquée à notre série, la différence n'est pas retrouvée. La cause en est probablement encore une fois l'accident B, qui comporte à lui seul 72% des décès.

Routes de sortie : Aucun des rapports de la Marine Nationale ne fait état de difficultés à identifier les issues, peut être parce qu'il s'agit dans tous les cas d'appareils de petite dimension (LYNX-WG13 et ALOUETTE II) à faible proportion de passagers. On peut supposer que la formation donnée par l'ESSAN permet aux équipages de connaitre les routes de sortie. Le seul qui aurait pu avoir des difficultés est le passager de l'accident G; le comportement adapté du treuilliste lui a permis de ne pas avoir de problème. Il est probable que cette difficulté doit être majeure dans les hélicoptères de transport, pour lesquels l'entraînement des passagers ne peut être fait.

Préparation du vol : La préparation du vol a très probablement été défectueuse dans le cas B. En effet, ce vol se faisait au profit de sujets habitués à transiter en hélicoptère, et le briefing a peut être été écourté. Il est étonnant que, alors que l'amerrissage a été assez doux, le "chef cargo" ne se soit pas immédiatement occupé de repérer le matériel de survie (problème de panique ?). D'après le rapport : "un des passagers extrait de l'appareil un "colis orange" non arrimé qu'il pense être le matériel de sauvetage; ce dernier coule immédiatement". Ce passager n'a pas pu identifier le matériel en question, c'est donc que personne ne lui a indiqué où trouver le matériel de survie dans cet appareil. A la deuxième tentative, l'hélicoptère avait cabané et personne n'a pris le risque de pénétrer à l'intérieur de la cellule envahie par l'eau. La connaissance insuffisante des matériels de survie par le personnel embarque a sans doute joué un rôle déterminant dans le bilan humain de cet accident.

Inhalateurs d'évacuation : Devant la fréquence des évacuations sous l'eau, Brooks propose l'utilisation d'inhalateurs d'évacuation. Ces matériels sont certes intéressants, en ce sens qu'ils limitent le risque de panique. Cependant, deux problèmes peuvent de se poser : danger de surpression pulmonaire, si le sujets panique et ferme sa glotte pendant la remontée ; gêne occasionnée par cet équipement.

Le premier risque est surement minimisable par l'entraînement, puisque le comportement adapté est acquis lors de l'apprentissage par les plongeurs (les exercices comportent de tels types de remontée). Sur ce dernier point la controverse reste ouverte sur le rapport utilité/risque de ce type d'entraînement.

Le deuxième point, est plus complexe et relève de l'ergonomie. La gêne peut apparaître lors :

- du port permanent (encombrement, poids); ce point peut être résolu par l'utilisation de systèmes à très haute pression (>300 b) en technologie moderne ; cependant, la taille du détendeur nécessaire semble actuellement difficilement réductible.

- de l'évacuation, par l'encombrement de l'ensemble bouteille-détendeur, avec le risque de s'accrocher au passage ; ce point peut être minimisé par l'intégration de l'inhalateur au gilet de sauvetage.

- de l'entretien (vérification de gonflage préalable de la bouteille, etc...), mais ceci sort du cadre de cette étude.

La fréquence des évacuations sous l'eau pose la question de l'investissement pour la probabilité d'utilisation. Dans notre série, il aurait peut-être pu sauver 3 vies humaines sur les 39 mises en danger).

Emplacement des matériels de survie : Dans le cas B, l'emplacement des matériels collectifs de survie est manifestement inadapté : leur repérage a été impossible par un passager (non initié), l'extraction du matériel réel s'est avérée impossible après le retournement de l'appareil.

Une situation analogue a été décrite par Anton (accident G-BBHN). Dans les 2 cas, le retournement de l'appareil est en cause. La mise de cet équipement à l'extérieur serait certainement une excellente solution. Vue la fréquence des positions retournées, il faudrait placer ce matériel sous les cellules pour qu'il reste accessible ; se poserait alors la question de son amarrage : il doit être suffisamment solide pour résister aux contraintes, mais facile à larguer sans outil pour un sujet immergé dans l'eau froide.

Survie : Dans l'accident B, le problème essentiel a été celui de la survie en eau froide. Ce type de problème, bien que n'étant pas spécifiquement aéronautique ou lié à l'amerrissage des hélicopteres, a été la plus importante cause de décès dans notre série.

Récupération des Naufragés : la récupération des naufragés peut être un problème parfois insurmontable. Dans notre série, il est très fréquent que la récupération des survivants ne puisse être assurée que par des moyens de surface, les conditions météorologiques ne permettant pas le repérage et encore moins le treuillage des naufragés.

CONCLUSION

Cette étude, très fractionnaire, montre que les accidents d'hélicoptères au dessus de l'eau dans la Marine Nationale sont peu fréquents. L'un d'entre eux mis à part, le taux de survie est élevé.

Elle retrouve les principaux facteurs de gêne à l'évacuation décrits par Brooks, avec cependant une moindre gêne à l'évacuation.

L'évacuation subaquatique semble la règle pour le LYNX-WG13, alors qu'elle est exceptionnelle avec les autres appareils. Ceci pose la question de l'adaptation de l'entraînement (qui ne semble pas poser de problèmes aux équipages, mais peuvent exceptionnellement en poser pour les passagers), des équipements de vol (port des combinaisons étanches pour les passagers), des matériels d'évacuation (mini-appareil respiratoire de secours intégré dans la brassière par exemple) et de l'emplacement des équipements de survie (à l'extérieur de la cellule), etc...

Elle demanderait à être étendue sur une période plus longue pour :

- atteindre des effectifs statistiquement significatifs,

- envisager le rôle des conditions de vol, des types d'appareils et des différents équipements,

- tenter d'évaluer l'apport de la mise en service de l'ESSAN sur les possibilités de survie.

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HELICOPTER CRASH SURVIVAL AT SEA-
UNITED STATES NAVY/MARINE CORPS EXPERIENCE 1977-1990

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SUMMARY

This paper examines the United States Navy/Marine Corps' (USN) experience with helicopter Class A over water mishaps for the period from 1977 to 1990. There were 137 helicopter Class A flight mishaps over water during this period with an overall survival rate of 83% in survivable water crashes. During this period, the USN developed several programs to improve survivability. The helicopter water survival training device (WSTD or 9-D-5 device) was instituted in 1982. The helicopter emergency escape device system (HEEDS) and the helicopter emergency lighting system (HEELS) were implemented in 1987.

This study attempts to answer the question whether or not these programs have, in fact, improved survival since their implementation. In addition, the study reviews the types of operational problems encountered with these devices. The results indicate that the WSTD and HEEDS may have contributed to the statistically significant improved survival seen among Navy aircrew in night crashes. They may have also contributed to the improvement (not statistically significant) in survival among passengers in night crashes. The data were inconclusive with respect to the effects of HEELS because of its not being implemented throughout the fleet. Operational problems with these devices were minor and the benefits of each program far outweigh any risks. In fact, in night crashes aircrew had significantly higher likelihood of survival than passengers who were essentially untrained occupants. Other factors, in addition to the devices studied, may have also affected survival probabilities.

1 INTRODUCTION

Survivability in aircraft mishaps is usually a function of impact force magnitude and post crash environmental factors. Helicopter crash impact forces are often significantly less than fixed wing aircraft. As a result, a substantial portion of helicopter impacts are potentially survivable. However, when reduced impact forces are combined with water entry, the post crash environment presents unique challenges to the survivors. Crew and passenger escape are related to a multiplicity of factors, especially the actual egress from the aircraft.

Escape may be hampered by the sheer bulk of equipment worn, by problems in releasing restraint systems, or by difficulty in or inability to release or open escape hatches or windows. The individual crew member or passenger may be unable to reach emergency exits due to obstructions, equipment hang-up, unusual aircraft attitude, or personal injuries. Indeed, survivors may become trapped in the aircraft. Although these factors are not unique to the water, they are certainly magnified at sea. Impact at sea is associated with the additional problem of an immediate in-rush of water. It may be dark, even in the day-time and it is frequently cold. The survivor will often experience confusion and disorientation. This may be compounded by injuries sustained during the initial dissipation of crash energy. He or she may be dazed, injured or rendered unconscious. There may be problems with fire, smoke, or fuel, although these are infrequent complications at sea. All of these problems have been well documented by other investigators (Refs 1 & 2).

During the past decade, the USN has implemented several programs in an attempt to reduce the overall mortality and morbidity associated with helicopter over water crashes. In 1981 the USN initiated a multi-place helicopter water ditching training program using the 9-D-5 Water Survival Training Device, the so-called "helo-dunker" (WSTD). The WSTD exposes aircrew to a series of simulated helicopter water impact scenarios and teaches the skills necessary for successful egress.

In 1987 the USN introduced the Helicopter Emergency Egress Device System (HEEDS) fleet-wide. This is an emergency breathing system that gives the aircrewman up to three minutes of air during the critical post-impact period. When one considers the rapidity with which most helicopters sink after water crashes, three minutes may make all the difference.

Also, in 1987 the USN began retrofitting its aviation fleet with the Helicopter Emergency Egress Lighting System (HEELS). This system is actuated at the time of impact or shortly thereafter by contact with water. It is strategically placed to indicate the route to and location of the main emergency exit.

The USN developed these systems as an integrated package to address the most pressing problems identified in helicopter water impacts. The WSTD would reduce the degree of panic, confusion and disorientation during attempted escape, HEEDS would provide sufficient time to reach the exit and HEELS would "light the way."

This study attempted to answer two questions. First, have these survival interventions (i.e., the WSTD, HEEDS, and HEELS) reduced the mortality/morbidity rates from over water helicopter crashes? Second, what kinds of problems have arisen and been documented in using these systems?

2 METHODS

The analysis was restricted to helicopter data for 1977-1990. For baseline comparison, we initially determined the total number of over land and over water helicopter Class A flight mishaps and their corresponding survival rates for the period in question (1977-1990). A Class A flight mishap is defined as one in which a naval aircraft was destroyed or the cost was over one million dollars of damage or there was loss of life or permanent total disability. Survival rates were computed both for Naval Aviation as a whole (Navy and Marine Corps) and for the individual services.

Over water helicopter crash data were then separated into three time periods to note the introduction of training modalities to be examined. Data were examined for 1977 through 1981 (P1), prior to introduction of the programs in question, for 1982 through 1986 (P2), after full implementation of the 9-D-5 trainer and for 1987 through 1990 (P3), after full implementation of the HEEDS program. No such evaluation was possible for HEELS, since the program has yet to be implemented fleet-wide. Only the Navy's H-60's and the Marine Corps H-46's have been completely refitted with HEELS. All other Navy and Marine Corps helicopter types remain in some stage of HEELS retrofit.

The narrative of each over water mishap was examined to determine the problems, if any, created by each of the above safety interventions. Specific data on HEEDS were available in the Naval Safety Center Data Base. Data on operational problems encountered with HEELS were also available in the Data Base. For the 9-D-5 trainer, reports were analyzed from the Water Survival Training Model Manager located at the Naval Schools Command (Ref 3). The data were then converted into incidence of problems per 100,000 training evolutions. Finally, we applied statistical tests to determine if survival probabilities changed significantly across the time periods. We also compared United States Navy/Marine Corps over water statistics for differences in survival likelihoods.

3 RESULTS

During 1977-1990 there were 268 helicopter Class A flight mishaps, 131 over land and 137 over water. There were 721 occupants in the over land mishaps. Of these, 64% survived. The survivors included 67% of the 468 aircrew and 59% of the 253 passengers. The over water mishaps involved 638 occupants. The survivors numbered 70%, which consisted of 72% of the 499 aircrew and 60% of the 139 passengers.

The 137 over water crashes, which involved 138 occupied aircraft, included 115 survivable aircraft. A survivable aircraft is one in which at least one person survived. There were 537 occupants in these survivable aircraft. Of these, 83% survived. The survivors included 86% of the 418 aircrew and 71% of the 119 passengers.

Table I summarizes the results of the study of all survivable over water Class A helicopter flight mishaps. Statistical tests of significance were performed to test the hypothesis (Ho) that survival probability was independent of time against the hypothesis (H1) that survival probability and time were dependent. Ho was rejected in this analysis and results were defined to be "statistically significant" if the descriptive significance level, p, was less than .10. Tests were performed first for survivable over water crashes with time divided into 1977-1981 (P1), 1982-1986 (P2), and 1987-1990 (P3). The tests were performed on statistics stratified by aircrew and passengers, for Navy/Marine Corps combined, for Navy and Marine Corps separately, and for day versus night.

The stratifications were essential because of mission, aircraft, and policy differences between the services. The Marine Corps helicopter fleet consists primarily of the H-1, H-3, H-46, and H-53, while the Navy flies the H-1, H-2, H-3, H-46, H-53, H-57, H-58, and H-60. Throughout 1977-1990, the Navy has forbidden passengers on night helicopter operations. The Marine Corps' policy was the same until 1982 when amphibious missions required transporting troops ("passengers") under the "cloak of darkness."

Referring to Table I, there were statistically significant relationships between survival probability in Navy night as well as Marine Corps day over water survivable crashes and time period. Aircrew survival probabilities in Navy night crashes significantly increased from 79% (31 of 39) to 85% (52 of 61) to 94% (31 of 33) during P1, P2, and P3 respectively. However, both Marine Corps aircrew and passenger day crash survival probabilities significantly decreased from P1 to P2. There were no Marine Corps over water survivable day crashes during P3. The Marine Corps aircrew day survival probabilities during P1 and P2 were 92% (24 of 26) and 67% (6 of 9) respectively. The Marine Corps passenger day survival probabilities during P1 and P2 were 100% (10 of 10) and 67% (12 of 18) respectively.

Statistical tests were also performed on over water survivable crash data across the 1977-1990 period where Ho: Survival probability was independent of (a) day, night; (b) aircrew, passenger; (c) Navy, Marine Corps against H1: Survival probability and (a); (b); (c) are dependent. Specific statistically significant relationships were observed. Both aircrew and passenger survival probabilities were significantly higher in day crashes than in night crashes for the Navy/Marine Corps combined (90%-234 of 260 vs 80%-127 of 158 for aircrew: day vs night and 88%-73 of 83 vs 31%-11 of 36 for passengers: day vs night). The differences were particularly large in the Marine Corps (86%-30 of 35 vs 52%-13 of 25 for aircrew: day vs night and 79%-22 of 28 vs 31%-11 of 35 for passenger: day vs night). Aircrew were also significantly more likely than passengers to survive night crashes Navy/Marine Corps combined (80%-127 of 158 vs 31%-11 of 36).

Comparisons between Navy and Marine Corps over water survivable Class A flight mishaps show that occupants of Navy aircraft were significantly more likely to survive than occupants of Marine Corps aircraft regardless if day or night or aircrew or passenger (89%-369 of 414 occupants in Navy aircraft survived while 62%-76 of 123 occupants in Marine Corps aircraft survived).

Statistical analysis of all Navy/Marine Corps Class A flight mishaps, survivable and non-survivable combined, showed that the probability of survival in over land crashes did not change significantly during P1, P2, and P3 for either aircrew or passengers (66%-153 of 232, 76%-91 of 120, 61%-71 of 116 for aircrew; 59%-53 of 90, 55%-45 of 82, 63%-51 of 81 for passengers). However, aircrew survival probability significantly declined in over water crashes with a larger decrease occurring in P3 over P1 and P2 (76%-123 of 162, 78%-155 of 198, 60%-83 of 139 for P1, P2, and P3 respectively). The passenger survival probabilities in over water crashes decreased after P1, but the decreases were not statistically significant (77%-20 of 26, 50%-34 of 68, 67%-30 of 45 for P1, P2, and P3 respectively). Finally, the probability of aircrew surviving an over water crash (72%-361 of 499) was significantly greater than surviving an over land crash (67%-315 of 468). The difference for passengers (60%-84 of 139 over water vs 59%-149 of 253 over land) was not statistically significant.

The p values throughout the analysis must be interpreted in view of the dependency of the data sets and the performance of multiple statistical tests.

Review of narratives of all over water crashes in which HEEDS was a factor in the egress phase of the mishap indicated 25 "saves." A "save" was defined as an individual who perceived that he or she would not have survived without the use of HEEDS. This was determined by review of survivor statements made to investigation boards.

Finally, there were problems reported during 9-D-5 training and with operational use of both HEEDS and HEELS. Since 1981, there has been one death reported related to 9-D-5 training. For the one year (1991) for which fleetwide reports were required, there were no major injuries reported with 9-D-5 training; there were a total of 17 minor injuries. The incidence of minor injuries was 28.3/100,000 evolutions. There were a total o 60,000 training evolutions conducted in 1991 fleetwide. Minor trauma was the most common injury at 41.2% of all minor injuries--an incidence of 11.7. Table II summarizes these data for the 9-D-5 trainer.

There were only two HEELS incidents reported; both occurred in 1989. One was an "actuation failure" in a H-3 and the other, a "difficulty in locating" in a H-2.

There were 19 aircrew who reported a total of 21 problems with HEEDS use during helicopter Class A flight mishaps from 1987-1990. Of these, the most common were "Needed, not used" (4), "Donning/Removal" problems (5), and "Needed, not available" (5). Table III lists HEEDS problems coded by the Naval Safety Center.

4 DISCUSSION

Overall Survivability

Although the data show that there was no significant increase in the probability of survival for total Navy/Marine Corps aircrew in over water Class A survivable helicopter flight mishaps over the periods examined, there was a significant increase in the probability of survival from P1 to P2 to P3 for Navy aircrew in night over water mishaps. This suggests the programs studied may have contributed to the increase in survival probability of this group.

During P1, the number of night-time, passenger carrying missions was almost non-existent. The situation changed in 1982 with the decision to use night vision devices as a means of improving American night-fighting capabilities. Over the next few years, as the Marine Corps developed its night assault and insertion doctrine, night passenger carrying missions increased dramatically.

The improvement, though not statistically significant, seen in percent survival of night passengers from P2 to P3 may be attributed to several factors. First, when the Marine Corps initially began over water night-time personnel helicopter movements in 1982, troops ("passengers") routinely wore combat gear during over water flight. The bulk of this equipment rendered emergency egress through hatches and windows almost impossible. Many Marine Corps units now require this gear be stowed and donned just prior to disembarkation.

Second, the wearing of restraints while passengers were seated in flight was poorly enforced. If an over water inflight emergency did arise, it was quite likely that a substantial number of passengers would impact the water while unrestrained. It is almost impossible to keep a reference point or maintain orientation during unrestrained impact. Procedures now require the crew chief to brief passengers on strict compliance with all restraint regulations. Finally, since passengers are not formally trained in water survival, they are usually unfamiliar with the methods for safe egress from a sinking helicopter. The Marine Corps has recently instituted basic water survival training for ground forces prior to over water helicopter operations.

The 9-D-5 Device

Did the introduction of the 9-D-5 increase the probability of survival of over water survivable helicopter crashes? Considering only aircrew members, there was significant improvement in the night Navy aircrew survival from P1 to P2 to P3. This suggests the 9-D-5 training program has had a positive impact on the survival of this group. Furthermore, narrative reports prepared by aircrew mishap survivors generally indicate that water survival training was an important, positive factor in the immediate post-crash water environment.

Water survival training involves much more than just the multi-place 9-D-5 trainer. The program includes swimming, using several strokes in full flight-gear for certain distances, treading water for a fixed period of time and "drown proofing" over a considerable time. It also includes trainee identification and utilization of all available survival gear, as well as training with other devices. These include the parachute drag, water entrance via the "slide for life", the parachute disentanglement device and the rescue procedures demonstrator.

Admittedly, not all of this experience is directly related to helicopter egress. However, the trainee receives considerable time in the water environment dealing with simulated survival activities. This experience serves to minimize the novelty of the water egress, instilling confidence which may help reduce initial panic.

Although the data indicate there was not an overall improvement in survival for total Navy/Marine Corps aircrew, it can not be concluded that the device has not made a positive contribution to overall survivability. The water survival program must, in the final analysis, be considered as a whole. Generally, it appears this type of training has saved lives.

Since its introduction, there has been one 9-D-5 associated fatality, a drowning victim at Pensacola. Overall, there have been only minor problems incurred during 9-D-5 device training. The data are somewhat limited, since central reporting was not required prior to fiscal year 1991 (FY 91). See Table II. Reports for that year show only minor injuries, the majority of which were blunt trauma sustained by contact with the device or with other trainees in the process of egress. Water aspiration was minimal in the few cases reported and did not lead to other, more serious complications. Minor muscle strains were the second most commonly reported injuries (Ref 3). Given the type of training and the level of physical intensity required, these kinds of injuries are not unexpected. The overall benefits of the training appear to outweigh the slight risk of injury.

The HEEDS Program

Did the introduction of HEEDS improve survival? The data suggest that HEEDS may have contributed to the significant improvement in survival probability seen from P1 to P2 to P3 in Navy aircrew on night over water crashes. In addition, based on aircrew narrative reports, it is clear that the HEEDS device has facilitated water escape. Individuals consistently reported a calming effect with the use of HEEDS, replacing the post-impact panic frequently experienced with the initial inrush of water, cold shock, and disorientation. With HEEDS use, the aircrew has additional time to help passengers safely egress. The Marine Corps is seriously considering training ground troops in HEEDS use and supplying the device for over-water missions.

Most of the problems encountered with HEEDS can be attributed to the device's procurement history. Acquired as an add-on to the already existing survival vest, the long, bulky oxygen canister replaced an unrelated piece of equipment in the vest left, front pocket. To hold it in place, it was attached by a lanyard. There have been reported problems with both removal and the initial donning. On occasion, the device was lost because the lanyard was not secured, or was absent altogether. There are several reports of minor injuries from contact with the device. There will soon be available a more compact version, ultimately replacing the present system. However, availability problems due to aircrew failure to properly pre-flight personal gear or paraloft error, such as failure to attach the restraining lanyard, will continue. In an attempt to minimize these types of human errors, the U. S. Coast Guard recently redesigned the device. In their version, the cylinder is an integral part of the survival vest with long, flexible tubing and a mouth-piece attached. Only the mouth-piece need be located, retrieved and brought to the mouth for use.

Parenthetically, the institution of HEELS may also have contributed to the improvement seen in passenger survival. However, there are insufficient data on the actual use of HEELS in class A flight mishaps over water to make any definite statements.

5 CONCLUSIONS

Although there has been no significant increase in combined Navy/Marine Corps over water survivable Class A helicopter flight mishap survivability during the period examined, data show that there was a statistically significant increase in probability of survival for P1 to P2 to P3 for Navy aircrew in night survivable crashes over water. This suggests that the 9-D-5 device and HEEDS both may have had positive effects on the probability of survival of this subgroup. The environment in which these mishaps occur continues to evolve. As more and more operations are conducted at night, the risk of fatality in an otherwise survivable impact becomes greater. The institution of 9-D-5 training as part of the Water Survival Training Program (WSTP) may have contributed to the relatively stable combined Navy/Marine Corps aircrew survival during the period examined. The 9-D-5 training closely simulates the post-water impact environment and aircrew members learn the skills required for survival. The benefits of such training far outweigh the risks. The WSTP should become part of the required training for Marine Corps personnel involved in regular over water evolutions.

Because aircrew with HEEDS have more time to help passengers escape, the HEEDS may have been partially responsible for the apparent increase in percent survival for Navy/Marine Corps night passenger survival seen from P2 to P3. Most of the problems reported with using this device seem easily correctable and training in HEEDS use should be extended to special categories of passengers that are at very high risk, e. g. Marine Corps ground troops transported by helicopters during amphibious operations.

There are insufficient HEELS data, but interviews with survivors continue to emphasize the visual difficulties encountered during water egress, especially at night. It seems most likely emergency lighting will help.

ACKNOWLEDGEMENTS

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Table I - Survival Data by Study Group*

	CY 77-81		CY 82-86		CY 87-90	
SURVIVORS	No.	(%)	No.	(%)	No.	(%)
Navy Aircrew Day	65/72	(90%)	93/100	(93%)	46/53	(87%)
Navy Aircrew Night	31/39	(79%)	52/61	(85%)	31/33	(94%)
Marine Aircrew Day	24/26	(92%)	6/9	(67%)	0/0	—
Marine Aircrew Night	3/3	(100%)	4/11	(36%)	6/11	(55%)
Navy/Marine Aircrew Day	89/98	(91%)	99/109	(91%)	46/53	(87%)
Navy/Marine Aircrew Night	34/42	(81%)	56/72	(78%)	37/44	(84%)
Navy Passenger Day	10/10	(100%)	19/20	(95%)	22/25	(88%)
Navy Passenger Night	0/1	(0%)	0/0	—	0/0	—
Marine Passenger Day	10/10	(100%)	12/18	(67%)	0/0	—
Marine Passenger Night	0/0	—	3/16	(19%)	8/19	(42%)
Navy/Marine Passenger Day	20/20	(100%)	31/38	(82%)	22/25	(88%)
Navy/Marine Passenger Night	0/1	(0%)	3/16	(19%)	8/19	(42%)

* Includes only over water survivable Class A Flight Mishaps.

Table II - 9-D-5 Trainer (CY 1991)*

PROBLEM	No.	%	Rate per 100,000 evolutions
Minor Trauma	7	41.2	11.7
Water Aspiration	5	29.4	8.3
Muscle "Strain"	2	11.8	3.3
Headache	1	5.9	1.7
Ear Problem	1	5.9	1.7
Laceration	1	5.9	1.7
TOTAL	17	100	28.3

* 15,000 students trained X 4 runs/evolution = 60,000 evolutions Navy/Marine Corps wide.

Table III - HEEDS

PROBLEM	No.	%
Needed, not used	4	19.0
Regulator broken, so didn't have	1	4.8
Donning/Removed	5	23.8
Improper procedures in use	2	9.5
Dislodged from vest, used	1	4.8
Caused minor injury	2	9.5
Needed, not available	5	23.8
Dislodged from vest, lost	1	4.8
TOTAL	21	100

CRASH EXPERIENCE OF THE U.S. ARMY BLACK HAWK HELICOPTER

by

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SUMMARY

The U.S. Army UH-60A, Black Hawk, helicopter is the first helicopter designed and built to modern crashworthiness standards. During the design of the Black Hawk, all common injury mechanisms were considered, and significant attempts were made to eliminate foreseeable injury hazards. Most important, the aircraft was designed to withstand an 11.6 m/s (38 ft/s) vertical impact without acceleration injury to the occupants or collapse of structure or high mass items into occupied space. Crew and passengers were provided energy attenuating seats and state-of-the-art restraint systems. Head strike zones were considered and potentially injurious objects excluded from these zones. Additionally, the helicopter was equipped with an advanced crash resistant fuel system.

First fielded in 1979, the Black Hawk now has accumulated over 1.1 million hours of flight time. Over the 11-year period from 1 October 1979 to 30 September 1990, there have been 75 class A and B mishaps of the UH-60 resulting in 84 fatalities and 121 personnel injured. Systematic analysis of these crashes has accumulated adequate data to assess the effectiveness of the crashworthiness features of the Black Hawk. The Black Hawk has proven itself to be highly crash survivable even in impacts up to 18.3 m/s (60 ft/s) vertical velocity. Most notable have been its structural integrity, tie-down strength of seats and restraint systems, effectiveness of energy absorbing seats and landing gear, effectiveness of the crash resistant fuel system, and retention of high mass items. Mitigating against this has been a higher than predicted accident rate, a markedly increased vertical velocity at impact compared to most other helicopters in use by the U.S. Army, and a tendency for the roof to collapse in high vertical velocity crashes.

INTRODUCTION

In the design of a crashworthy vehicle, the primary objective is to control energy dissipation during a crash in such a manner as to prevent injury to occupants, irreparable damage to the vehicle, or a combination of both. From the perspective of injury prevention, there are five basic considerations: (1) Maintain a protective shell around all occupants throughout the crash sequence, (2) adequately restrain occupants so as to prevent injurious contacts with internal or intruding external objects, (3) limit the acceleration forces experienced by occupants to noninjurious levels, (4) provide an internal environment free of potentially injurious objects within the "strike zone" of occupants, and (5) control hazards that may prevent escape from the vehicle after the crash. The primary considerations in facilitating escape are to provide adequate numbers of exits, to ensure that those exits will function after a survivable crash, and to prevent postcrash fire.

Experience from aircraft crashes has shown that not all these considerations are of equal importance for personal survival [2,10,11,13,17,18]. However, all the factors are interrelated and consideration must be given each to optimize crash survivability. For example, in helicopter crashes, the most critical consideration in preventing serious injury is to eliminate post-crash fires. This contention is supported by the fact that prior to the introduction of crashworthy fuel systems (CWFS) into U.S. Army helicopters, approximately 40 percent of fatalities in survivable crashes were due to thermal injury [8]. Since the introduction of CWFS, there has only been one documented death due to thermal injuries in a survivable crash of a CWFS equipped Army helicopter. Clearly, this single improvement has made a substantial difference in morbidity and mortality in crashes of Army helicopters. Nevertheless, the beneficial effects of a CWFS would be severely mitigated if occupants were fatally injured by collapsing structure or by failure of seats or restraint systems in potentially survivable crashes.

Understanding the interrelationship of the five basic crashworthiness factors is vital to aircraft system design since weight and economic factors frequently limit the degree of crash survivability that developers are willing to incorporate into an aircraft [9,10,18]. Certainly, crash survivability is not the most important consideration in the design of an aircraft, and weight and cost do limit the degree of crashworthiness that can be practically incorporated into a design. Nevertheless, when tradeoffs are made, it is imperative that developers understand the consequences of proposed compromises and ensure that all pertinent factors are weighed (cost, weight, performance, and safety) in these decisions.

The UH-60 Black Hawk was the first helicopter designed with crashworthiness as one the primary design objectives. It was introduced into the U.S Army fleet in 1979 and has been extremely successful both in terms of operational capability and crashworthiness in training and in hostile environments [16,17]. The success of this helicopter has proven that safety and performance are, in fact, compatible design objectives. Although crashworthiness has a significant cost in terms of weight and dollars, these costs are counterbalanced by a reduced injury rate and an increased threshold for damage to the aircraft. Over the life-cycle of the aircraft, these savings can be substantial [9,18].

This paper reviews the crash history of the Black Hawk, concentrating on the effectiveness of the various crashworthiness features incorporated into the design. Since the Black Hawk is the first helicopter designed to crashworthiness standards, it is useful to assess its performance to ascertain the adequacy of its various crashworthiness features in the operational environment. Such an assessment can lead to improved standards for future aircraft, recommendations for a retrofit program to enhance the crash performance of fielded aircraft, and recommendations for additional research to advance knowledge in crash protection.

BLACK HAWK DESIGN

The concept of building a crashworthy helicopter for the U.S. Army was borne out of experience gained in combat in Southeast Asia [15]. The helicopter had established itself in Army combat doctrine and many senior Army leaders had observed that lives were being lost in crashes when the technology existed to prevent many of these injuries. As a result, the Eustis Directorate of the U.S. Army Air Mobility Research and Development Laboratory commissioned the

Aviation Crash Injury Research Group of the Flight Safety Foundation to define the Army crash environment and develop concepts and design criteria to improve crash survivability. The culmination of this effort was "The Crash Survival Design Guide" (CSDG), now in its fourth edition, which has subsequently served as the basis of all Army crashworthiness standards [7].

The Black Hawk is a twin-engine utility helicopter designed primarily for transporting troops and supplies. It has a single four-bladed, fully-articulated main rotor system and a canted tail rotor. It utilizes two main landing gears and a single tail gear. Initially, it was designed to carry a crew of 3 with seats for 11 troops. More recently, it has been utilized to carry up to 22 troops without seating.

From the outset, the CSDG was used as a design guide for the development of the helicopter that was later designated the UH-60A Black Hawk. The primary crashworthiness design features included the following [3]:

1. Maintenance of the protective shell through a cabin superstructure designed to retain the engines and transmission under high load factors. Also, keel beams and a rounded nose were designed to prevent sudden longitudinal decelerations from plowing.

2. Seating and restraint systems designed to be retained under severe but survivable loads.

3. Energy attenuating landing gear and seating systems to maintain loads within survivable limits for impacts with vertical velocities up to 11.6 m/s (38 ft/s).

4. Provision of a noninjurious interior from upper body and extremity flailing.

5. Provision of a crashworthy fuel system with self-sealing fuel cells and frangible, self-sealing fuel and vent lines.

6. Provision of adequate emergency escape capability.

For details of these design features, the reader is referred to a paper by Carnell [3]. Table I summarizes selected design criteria for the Black Hawk that are pertinent to its crash survivability. It is important to understand that these criteria were adapted from the CSDG (TR 71-22) and were based on a study of selected U.S. Army light fixed-wing and helicopter crashes occurring in the early to mid-1960s. The overriding philosophy used to select these values was to prevent serious injury in crashes up to the 95th percentile potentially survivable crash. This is certainly a reasonable approach to establishing crashworthiness design criteria, but to be successful, it is dependent on one major assumption--that the crash kinematics of past aircraft designs accurately predict the crash kinematics of future aircraft designs. In the absence of any other predictive criteria, this is the only reasonable approach. How effective these criteria and concepts have been in the Black Hawk crash environment will be discussed.

Table I. UH-60A Key design requirements.

Structural integrity	
General:	TR 71-22 as a guide
MR blade strike:	8-in diameter object at outer 32% span without hazardous rotor or transmission displacement.
Longitudinal impact:	20 fps into barrier with livable cockpit volume, 40 fps into barrier with 85% cabin length retained, and 60 kt and 15° nose down with 85% volume retained.
Vertical impact:	38 fps with 85% cabin volume retained.
Lateral impact:	30 fps with 85% cabin volume retained.
Roll over:	4 G longitudinal, 4 G vertical, and 2 G lateral.
Mass item retention:	20 G longitudinal, 20 G vertical, and 18 G lateral.
Energy absorption	
Landing gear:	15 fps with gear damage only, 30 fps, 10° pitch and roll with gear and airframe damage.
Crew seats:	12-in vertical stroke, per MIL-S-58095.
Troop seats:	11-in vertical stroke, retained for 18 G longitudinal and 24 G lateral.
Postcrash	
Fuel tanks:	Crashworthy per MIL-T-27422 with frangible attachments.
Fuel lines:	Self-sealing, tear resistant with breakaway valves and fittings.
Emergency egress:	Within 5 seconds through doors, within 30 seconds through windows with aircraft on side.

BLACK HAWK CRASH STATISTICS

Since the Black Hawk was fielded in 1979 through September 1990 there have been 75 class A and B mishaps[1]. Of these, 48 involved a ground or water impact and had sufficient data available to be considered in this review. Nonground impact mishaps included various in-flight emergencies that severely damaged the aircraft but did not result in a crash, repelling accidents and ground mishaps such as fueling fires and collisions with other aircraft. There were a total of 271 individuals involved in ground impact mishaps, of which 84 suffered fatal injuries, 93 disabling injuries, and 28 nondisabling injuries. The U.S. Army defines a disabling injury as any nonfatal injury or combination of injuries that results in lost workdays for the individual. A nondisabling injury is any injury or combination of injuries that does not result in a lost workday. Table II provides comparison figures for UH-1 ground impact accidents over the same 11-year period.

Table II. Comparison of selected parameters in UH-60 and UH-1 ground impact mishaps.

Parameter		UH-60	UH-1
Number of mishaps:	Class A	40	142
	Class B	8	30
	Total	48	172
Mishap type:	Survivable	32	148
	Nonsurvivable	16	24
	Total	48	172
Occupant injury:	Fatal	84	116
	Disabling	93	294
	Nondisabling	28	102
	None	66	263
	Missing	0	1
	Total	271	776
Mean velocity at impact:	Vertical	44.2	17.7
	Longitudinal	46.4	31.6

Figure 1 shows combined class A and B mishap rates for the two helicopters over the same period. Figure 2 shows a similar comparison for ground impact mishaps only. Note the comparatively high mishap rate for the UH-60 during its early years in service and how this rate has shown a progressive decline since 1985. Over the same period, the UH-1 rate also has decreased, but at a significantly lower rate. This initially high rate followed by a progressive decline is typical of newly fielded systems, particularly when the new system represents a significant increase in complexity over the system it replaces. A large proportion of the early mishap rate can be attributed to the "learning curve" associated with developing new doctrine to exploit the full capabilities of the system and to difficulties in implementing new training and maintenance procedures as the system was fielded. The marked increase in crashes in 1991 was due to the massive deployment to Southwest Asia during Operation Desert Shield/Storm.

[1]The U.S. Army defines a class A mishap as a mishap for which the resulting total cost of property damage, occupational illness, or injury is $1 million or greater, or in which an injury results in a fatality or permanent total disability. A class B mishap is one for which the total cost is greater than $500,000 but less than $1 million.

INJURY STATISTICS

Table III shows that the risk for a major or fatal injury based upon person-hours of exposure remains considerably higher for the Black Hawk than for the UH-1 as has been previously reported [17]. An individual with a major injury is one who suffered permanent total disability or permanent partial disability. The relative risk for fatal injury as well as for fatal and major injury combined is 3.8 times greater for the Black Hawk. This is due to the comparatively high crash rate for the Black Hawk as well as to the increased severity of UH-60 crashes.

Although one's overall risk of injury is greater in the UH-60, this type analysis is somewhat irrelevant in ascertaining the efficacy of crashworthiness design standards. To compare levels of crashworthiness, one should ask, "For a given impact velocity change, which airframe provides a higher level of occupant protection?" When viewed from this perspective, it becomes evident that the UH-60 provides a substantial increase in crash protection over conventionally designed helicopters, of which the UH-1 is an example.

The most important factor relating to the crash performance of the Black Hawk is its propensity to crash at extremely high

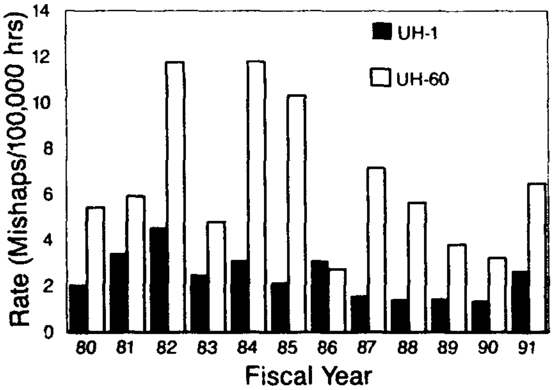

Figure 1. UH-60 and UH-1 class A and B mishap rates per 100,000 hours flight time for FY 80 - 91.

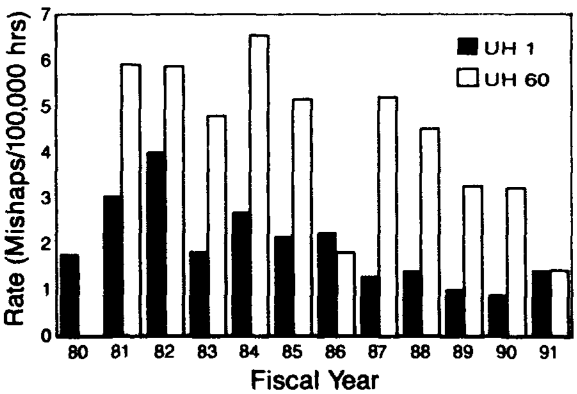

Figure 2. UH-60 and UH-1 class A and B ground impact mishap rates per 100,000 hours flight time for FY 80 - 91.

Table III. Comparison of fatal and fatal/major injury rates for the UH-1 and UH-60.

Parameter	UH-1	UH-60
Total flight hours	8,411,301	1,267,648
Number of occupants	776	282
Injuries:		
Fatal	117	84
Major	20	13
Fatal injuries		
Rate (per 100,00 flight hours)	.31	1.18
Relative risk	1.00	3.80
Fatal and major injuries		
Rate (per 100,00 flight hours)	.36	1.37
Relative risk	1.00	3.80

velocities in comparison to the UH-1 (Table II). This is particularly pronounced for vertical velocities where the mean velocity at impact for the UH-60 is two and a half times that of the UH-1. Since injury in helicopter crashes is highly correlated with vertical velocity change [16,17] and since crashworthiness design standards for the UH-60 were based on the assumption that it would have essentially the same crash kinematics as earlier generation helicopters, the overall injury rate in Black Hawk crashes appears disappointingly high. If, however, velocity at impact is considered, it is readily apparent that the crashworthiness features incorporated into the Black Hawk are extremely effective.

Figure 3 is a plot of vertical velocity at impact versus cumulative percent occurrence of survivable class A and B mishaps for the UH-60 and UH-1. This graph clearly demonstrates the greater tolerance of the UH-60 to high vertical velocity impacts. Note that over 50 percent of survivable UH-1 crashes occur at vertical velocities of less than 3.0 m/s (10 ft/s), whereas only 15 percent of UH-60 crashes occur at less than 3.0 m/s (10 ft/s). Additionally, the 95th percentile survivable vertical velocity for the UH-60 is 15.2 m/s (50 ft/s) versus 10.7 m/s (35 ft/s) for the UH-1. In other words, crashes of the Black Hawk are classified as survivable up to vertical velocities of 15.2 m/s (50 ft/s) compared to 10.7 m/s (35 ft/s) for the UH-1. The increase in kinetic energy for impacts of 10.7 m/s (35 ft/s) versus 15.2 m/s (50 ft/s) is over 100 percent.

Since survivability of a crash is determined independently of injuries sustained in the crash, it is useful to compare injury

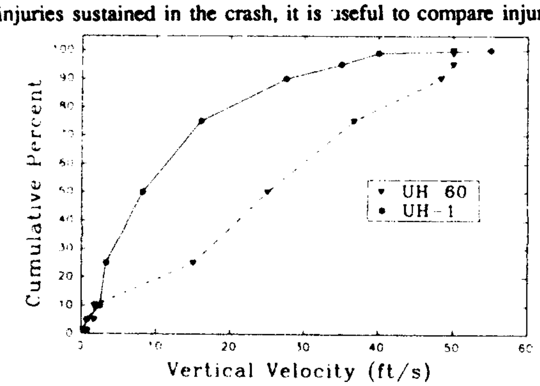

Figure 3. Plot of vertical velocity at major impact versus percentile occurrence for all ground impact crashes of the UH-1 and UH-60.

rates for different crash severities determined by vertical velocity at impact. Figure 4 is a cumulative frequency plot depicting the total probability of sustaining a fatal injury over 1.5 m/s (5 ft/s) vertical impact velocity increments for the UH-1 and UH-60. Probability of death was determined by counting all deaths that occurred in each increment and dividing by total occupants exposed to crashes with vertical velocities within the increment. Interestingly, both helicopters clearly demonstrate a threshold velocity at which 100 percent of occupants receive fatal injuries. This occurs at approximately 12.5-13.7 m/s (41-45 ft/s) for the UH-1 and 18.6-21.3 m/s (61-70 ft/s) for the UH-60. The threshold for the UH-1 can be more accurately determined due to the greater number of UH-1 accidents. This depiction vividly illustrates the difference in crashworthiness levels between the two helicopters. The UH-60 is able to provide survivability at impact energies over two times that of a conventionally designed helicopter. When other levels of injury are compared, the exceptional crashworthiness of the Black Hawk is similarly demonstrated.

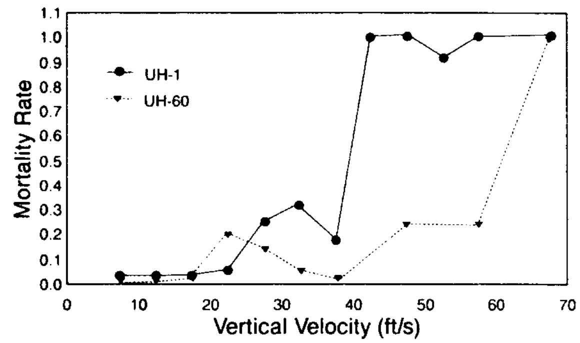

Figure 4. Cumulative frequency plot depicting the increasing probability of sustaining a fatal injury as vertical impact velocity increases for both the UH-60 and UH-1.

Table IV summarizes an analysis performed to determine whether there are significant differences in the distribution of major and fatal injuries between the Black Hawk and UH-1 in survivable crashes. This was done to assess whether the crashworthiness features incorporated into the UH-60 altered

Table IV. Percent of occupants in survivable ground impact mishaps receiving one or more major or fatal injuries to specified body region.

	All occupants		**Cockpit crew**	
Body region	**UH-1**	**UH-60**	**UH-1**	**UH-60**
General	0.3	1.5	0.7	4.7
Head	6.3	15.2*	8.5	17.2
Neck (soft tissue)	1.7	0*	2.0	0*
C-Spine	0.8	2.0	1.0	1.6
Chest	4.0	14.2*	3.4	14.1*
Vertebral	5.4	6.6	8.1	15.6
Abdomen	1.9	5.1	3.1	7.8
Arm	3.6	7.6	4.1	4.7
Leg	4.9	12.2	5.4	9.4

* Significant difference at p=0.05 confidence level

the distribution of injuries. For instance, it would be reasonable to speculate that the energy attenuating seats and landing gear should reduce the relative rate of spinal injury in the UH-60 compared to the UH-1. For this analysis, each occupant was assessed for major and fatal injuries and the location of his injuries. If he received one or more major or fatal injuries to a particular body region, he was assessed as having a single significant injury to that region, irrespective of the number of injuries in that region he actually sustained. There were significant differences in the distribution for head, neck and chest injuries between the two helicopters. Surprisingly, the rate of head and chest injuries was higher in the UH-60, and there was no reduction in spinal injury. The increased head injury rate in the UH-60 is probably related to the tendency for roof collapse in high vertical velocity crashes. The failure to see a reduction in spinal injury in the Black Hawk is probably because of the frequency of impacts that exceeded its design limits. The markedly increased chest injury rate has not been explained and will require more detailed study.

In summary, the crashworthiness design of the UH-60 has clearly proven its capability of preventing injury and death for impacts greatly exceeding its design limits. Unfortunately, this tremendous success has been somewhat overshadowed by its high mishap rate and its propensity to crash at velocities well beyond its design capability. In recent years, there has been a trend toward a lower mishap rate and also toward lower velocity impacts. If this continues, the overall injury rate for the Black Hawk should show some improvement in the next few years. Nevertheless, the crash history of the Black Hawk teaches an important lesson for the community engaged in crashworthiness design and aircraft development. To achieve an appropriate level of crashworthiness for a given system, it is essential to be able to accurately predict the crash environment of that aircraft while it is still under design. Overestimation leads to excessive costs and weight and underestimation leads to higher than anticipated injury rates. A major emphasis of future crashworthiness research should be to focus on this problem and to develop kinematic models that can predict crash velocities based on defined aerodynamic design parameters.

CRASHWORTHINESS PERFORMANCE

Irrespective of statistical analyses of injury in the Black Hawk, it is useful to take a more qualitative approach to examine how the various crashworthiness features incorporated in the Black Hawk have performed under crash conditions. The following is a perspective of these features based upon personal experience in investigating over 25 Black Hawk crashes over the past 11 years combined with a record review of the remainder of the crashes.

Fuel System

There has not been a single fatality due to thermal injury in crashes of the Black Hawk. The system has performed exceedingly well under crash conditions well in excess of structural design limits including several crashes with vertical velocities exceeding 18.3 m/s (60 ft/s). In several cases, the fuselage has ruptured allowing the fuel cells to separate from the aircraft without significant spillage (Figure 5). In one case, a Black Hawk impacted the ground with a vertical velocity of 12.2 m/s (40 ft/s) and a longitudinal velocity of 23.8 m/s (78 ft/s). The helicopter broke apart and a slowly spreading fire ensued from a leaking fuel line. In spite of the fire, rescuers were able to extract all six occupants without any occupants receiving thermal injuries. Considering the structural damage to the aircraft, this could not be considered a failure of the CWFS. Under these circumstances the CWFS is designed to prevent a sudden and overwhelming fire, thus allowing survivors sufficient time to escape before occupied areas are engulfed in flames.

Figure 5. Crash of a MEDEVAC equipped UH-60 occurring at 15.8 m/s (52 ft/s) vertical velocity and 3.7 m/s (12 ft/s) longitudinal velocity. Roof completely sheared off and is lying beside fuselage. Note the stretcher to the left of the photograph and an exposed, but fully intact fuel cell in the foreground.

Figure 6. Black Hawk crashed with vertical velocity of 18.3 m/s (60 ft/s) and longitudinal velocity of 4.6 m/s (15 ft/s). Note almost complete roof collapse. Three of four occupants survived.

Structure

Basic structural crashworthiness of the Black Hawk has proven itself by exceeding its design limits in numerous crashes [15,16,17]. High mass item retention has been remarkable. Of particular note, there has never been an intrusion of the rotor system into occupied spaces. Likewise, in survivable crashes, neither the engines nor the transmission have ever dislodged and intruded into occupiable spaces.

One persistent problem has been identified. The roof of the Black Hawk begins to collapse in crashes where the vertical velocity at impact exceeds 12.2 m/s (40 ft/s). In impacts exceeding approximately 13.7 m/s (45 ft/s), the roof completely separates aft of the pilot stations and collapses into the cabin creating a hazard for pilots as well as passengers (Figure 6). Although roof collapse occurs at velocities beyond design limits, it constitutes the most serious injury hazard for occupants in crashes with vertical impact velocities between 13.7 m/s (45 ft/s) and 18.3 m/s (60 ft/s). If roof collapse could be prevented, upright crashes of the Black Hawk would be survivable up to approximately 16.8 m/s (55 ft/s).

The mechanism of roof collapse appears to be related to the attachment of the upper portion of the main landing gear strut to the outer longitudinal beams in the roof (Figure 7). It appears that forces are concentrated at this attachment point causing the beams to fracture after the energy attenuating gear has fully stroked and fuselage-ground contact has occurred. A similar problem has been noted in the AH-64 Apache attack helicopter at the attachment point of the main gear to the longitudinal floor beams. These observations suggest that consideration should be given to using frangible fittings at these attachment points or using other means of attaching energy attenuating landing gear to main structure in future aircraft designs.

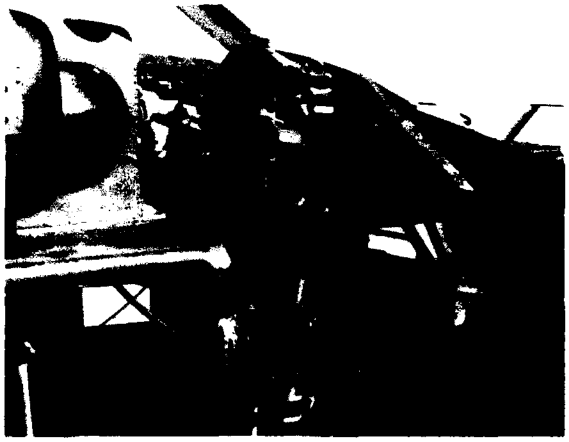

Figure 7. Photograph shows how upper mounting of main gear strut has separated main roof longitudinal beam allowing roof to collapse. Crash occurred at an estimated vertical velocity of 10.7 m/s (35 ft/s).

As a point of interest, it should be noted the stretcher carousel mounted in the cabin of UH-60s equipped for medical evacuation acts as a major support to the roof and prevents collapse into the cabin. In the only severe crash of a MEDEVAC UH-60 (Figure 5), the roof completely sheared off of the fuselage and came to rest beside the main wreckage. The carousel prevented the roof from collapsing into occupied spaces and both rear seated occupants survived with only minor injuries although the vertical velocity at impact was approximately 15.2 m/s (50 ft/s) and the longitudinal velocity was 6.1 m/s (20 ft/s).

MAIN LANDING GEAR

The concept of a rugged, fixed, energy attenuating landing gear has proven itself in crashes and hard landings in the UH-60. As Figure 3 illustrates, less than 30 percent of Black Hawk crashes occur at impact vertical velocities of less than 6.1 m/s (20 ft/s). A close inspection of those that do, reveals that they all occurred with significant pitch or roll or high rates of yaw beyond the design limits of the main gear. The gear is capable of preventing damage to the helicopter for landings up to 6.1-7.6 m/s (20-25 ft/s) provided the impact occurs on a hard surface with minimal pitch or roll. It is impossible to estimate the number of crashes that have been prevented by the gear, but anecdotal information from instructor pilots suggests that hard landings are not an uncommon occurrence in the training environment.

In addition, the main gear plays a significant role in the total energy management scheme for near vertical impacts of the Black Hawk. They provide approximately 23 inches of stroke at a 9G average acceleration before fuselage-ground impact [3]. The capability of the gear undoubtedly plays a major role in the excellent crash survivability of upright crashes of the UH-60 at extremely high sink rates.

Crew Seats

The Black Hawk has been equipped with two different types of energy attenuating, armored crew seats. The original seat was a uniaxial stroking seat equipped with two inverted tube energy attenuators [3,4]. The seat was designed to provide a minimum of 12 inches stroke at a load limit of 14.5 G. An additional 5 inches of stroke could be obtained depending on the vertical adjustment of the seat. To achieve this stroke distance, a well was provided beneath the seat into which the seat could stroke (Figure 8). The tie-down strength of the seat was provided in accordance with MIL-S-58095 (5). The restraint system was a 5-point configuration with a rotary release mechanism.

Figure 8. Closeup photograph of a crew seat involved in the crash shown in Figure 5. Note how seat stroked into the well and the top of the seat is below floor level.

This seat has provided superior performance in Black Hawk crashes up to 18.3 m/s (60 ft/s) vertical impact velocity. The seat has been consistently retained in place in all potentially survivable crashes. In the crash shown in Figure 9, seat retention and its energy attenuating capability were determined to be the primary contributors to the survival of both pilots when most of the surrounding structure had disappeared. Several similar UH-60 crashes have proven the importance of providing seat retention capability in excess of estimated human tolerance limits.

An additional, although serendipitous, feature of the original crew seat is illustrated in Figure 10. Note that the seat was designed to stroke downward along its two parallel support tubes. The support tubes are linked to the energy attenuators at the top, forming a structure that acts as a roll-bar above the head of its occupant after the seat strokes. In five crashes of the Black Hawk where the roof completely collapsed, this structure was responsible for preventing major head injuries to the occupants of the seats.

Approximately 250 aircraft were equipped with this seat before it was replaced with the current seat in a cost-saving move. The current seat is equipped with six TOR SHOK™ attenuators that permit the seat to stroke along three axes

Figure 9. Closeup photograph of crash shown in Figure 6. Note full retention of crew seats although little cockpit structure remains.

Figure 10. Pilot seat from crash described in Figure 5. The roof collapsed onto the seat but was supported by the seat frame. The stroking of the seat positioned the pilot's head well below the collapsed roof.

(Figure 11). Studies have shown that the seat has a somewhat stiffer response in the vertical axis and early indications are that it may have a slightly higher spinal injury rate for similar severity crashes [12,15]. Its multiaxis stroking capability also tends to prevent it from stroking into the well except in pure vertical loading crashes. In addition, its design does not provide for overhead protection from a collapsing roof. In spite of these potential deficiencies, this seat has performed well in the Black Hawk crash environment.

Figure 11. Current Black Hawk crew seat viewed from the rear. Note the absence of a frame capable of supporting a collapsing roof.

With recent advances in energy attenuating seat technology, several U.S. Army agencies are advocating changing applicable specifications to provide for a new generation seat restricted to a uniaxial stroke and equipped with variable load energy attenuators [15]. It also could be tailored to provide for special requirements such as overhead protection or even be equipped with airbags.

Local Environment

Considerable attention was devoted to eliminating potentially hazardous objects from the strike zone of occupants in the Black Hawk. In general, there has been little problem with occupants receiving injuries from striking internal objects. However, there have been a few problem areas. As Figure 12 illustrates, the cyclic and collective controls remain a serious potential hazard particularly in the presence of a stroking seat. To date there have been no severe injuries attributed to cyclic strikes. However, one pilot lost several anterior teeth in one crash and at least five pilots have received contusions to the sternum (Figures 13 and 14). Although the sternal injuries have been minor, this injury is potentially life threatening if the strike is severe enough to cause cardiac contusion. The Army is considering designs for a frangible cyclic to help reduce this hazard, but it is doubtful such a device will be fielded.

Figure 12. Soldier posing in a crew seat that had stroked approximately 14 inches. Notice the proximity of the cyclic and collective controls.

Another recurring problem has been serious injuries arising from blunt impact against seat armor. Injuries have included severe head injuries, rib fractures and contusions, and closed and open arm fractures. This is a difficult problem to solve since the risk from projectiles is far greater in combat than the risk of blunt injury from contact with armor in a crash. In future designs padding could be considered but, due to technical considerations, is probably not likely to provide a solution. A more promising approach is to equip Army helicopters with inflatable airbag systems [1].

Figure 13. Cyclic control removed from crash with vertical velocity of 12.2 m/s (40 ft/s) and longitudinal velocity of 23.8 m/s (78 ft/s). Note linear gouges caused by pilot's teeth.

Figure 14. Photograph of sternal abrasion caused by contact with a cyclic.

Troop Seats
In the standard configuration, the Black Hawk is equipped with 12 troop seats. Each seat consists of an aluminum frame with fabric seat and back. The seats are roof and floor mounted and are designed to react to loads in both the vertical and longitudinal directions. Up to 11 inches of vertical stoking is provided by roof mounted wire bending energy attenuators. These attenuators bend preformed wire through an array of fixed rollers. Longitudinal forces are reacted through two additional wire bending attenuators mounted in diagonal struts positioned under the seat frame. Each seat is provided with a four-point restraint system consisting of lap belts and dual shoulder harnesses without inertia reels. To provide mobility, the two gunners wear a harness attached to the side-facing gunner's seats by three straps connected to inertia reels.

Black Hawk troop seats have been plagued by multiple problems in the crash environment which have been documented in a separate report to the program manager [14]. There have been failures of suspension and tie-down components, frame components, fabric and restraint system anchor points (Figure 15). Many of these problems have been corrected, but the fact remains that the energy attenuators have never performed as designed. None have stroked greater than 1 or 2 inches in a crash. This is partly because the attenuators are too stiff, and partly because the roof tends to collapse before they are able to stroke.

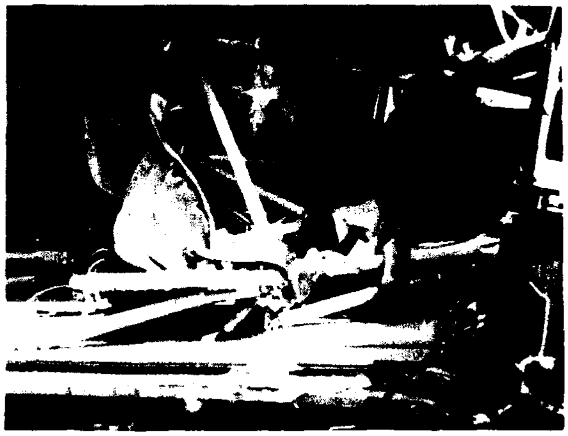

Figure 15. Photograph shows the cabin of a Black Hawk that experienced roof collapse during an upright crash. The roof can be seen at the top of the photograph and the floor at the bottom. Note the minimal space remaining between the roof and floor. The troop seats are completely collapsed.

In spite of these problems, the troop seats have been remarkably effective in preventing injuries. This has been so because they are suspended from the roof. The collapsing roof tends to act as a massive energy attenuator reducing inertial loads experienced by occupants of the troop seats. Additionally, since the seats collapse with the roof, the occupants are not struck by the roof until they have come to rest on the floor. This accounts for the high cabin survivability rates in spite of what appears to be total roof collapse (Figure 6).

If a decision is made to "fix" the troop seats, it is vitally important that the designers understand these interactions. For example, if a decision were made to install floor mounted seats without addressing the roof collapse problem, survivability rates would probably decrease because the seats would not collapse with the roof. Likewise, if the roof was strengthened, the energy attenuators would have to be redesigned and various other components would have to be strengthened to withstand the increased inertial loads.

CONCLUSIONS
This report is not intended to be critical of the Black Hawk, its manufacturer, or its designers. There is no question that

the Black Hawk is one of the most crashworthy helicopters in the world. It provides unparalleled crash survivability at impact velocities well beyond its design limits. This does not mean that its crashworthiness cannot be improved. Crashworthiness design is, by its nature, a trial-and-error process where innovations ultimately have to be tested and fine-tuned in fielded aircraft. The crash experience of the Black Hawk has shown that with relatively minor modifications to its structure and certain components, the Black Hawk's survivability envelope could be increased in the vertical axis to approximately 16.8 m/s (55 ft/s). It is for the user community to decide whether such modifications are necessary or cost-effective [9,10,15].

Regardless of design decisions made on the Black Hawk itself, this helicopter has provided the development community a wealth of information on crashworthiness design concepts. It has proven what works and what does not work, and an analysis of its successes and failures will lead to new concepts for future generation helicopters.

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U.S. ARMY HELICOPTER INERTIA REEL LOCKING FAILURES

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SUMMARY

The inertia reels utilized in U.S. Army helicopters are regulated by MIL-R-8236. This is a performance specification which requires the MA-6 and MA-8 inertia reels to automatically lock when the restraint strap is subjected to an acceleration between 1.5 and 3 G. A review of U.S. Army Safety Center, Fort Rucker, Alabama, mishap data revealed a number of critical and fatal injuries attributed to upper torso flailing that occur in survivable mishaps. Some of these injuries relate directly to the inertia reel either failing to lock or not automatically locking soon enough. Laboratory sled tests have revealed sporadic failures of the inertia reel in both its auto lock and manual lock positions. Inertia reel failures during high horizontal impacts are believed to be due to high rotational velocities of the ratchet wheel which may prevent the locking pawl from properly engaging the sprocket. Inertia reel failures during high vertical impacts are believed to be caused by the low forward acceleration (G_x) transmitted to the shoulder strap because of torso compression, rolling, and slumping. The lack of inertia reel maintenance and calibration procedures potentially allow the automatic lock sensitivity settings to drift to unacceptable levels over time. The influence of operational conditions (i.e., sand, dust, salt fog, temperature, humidity, etc.) on sensitivity settings are unknown. Field tests of 110 inertia reels at Fort Rucker, Alabama, airfields revealed a 24.5 percent failure to lock at the 3 G requirement. Corrective actions being considered include: (1) establishing calibration and maintenance procedures, (2) revising MIL-R-8236 to incorporate dynamic sled tests, and (3) development of an inflatable body and head restraint system.

INTRODUCTION

MA-6 and MA-8 inertia reels currently are installed in U.S. Army rotary-wing aircraft. These reels are regulated by MIL-R-8236 [1] which requires the reels to lock automatically when the shoulder harness webbing is subjected to an extension acceleration above 3 G. The reels must not lock at any strap acceleration below 1.5 G. Between 1.5 and 3 G is a grey area of tolerance where the reel may or may not lock. The specification also requires the reel to lock within 1.27 cm (0.5 inch) of strap movement after crossing the 3 G threshold. The only difference between the MA-6 and MA-8 inertia reels is the ultimate structural load the reels are capable of withstanding. This load is 4000 pounds for the MA-6 and 5000 pounds for the MA-8. There are other requirements for the MA-6 and MA-8 inertia reels, but the strap acceleration and extension thresholds are the primary requirements associated with aircrew restraint.

In accordance with MIL-R-8236, an inertia reel failure occurs either when it fails to lock at a strap acceleration of 3 G or a strap extension in excess of 1.27 cm (0.5 inch) occurs. In this paper, a more general definition of inertia reel failure is utilized, i.e., the inability of the inertia reel to prevent excessive torso motion during dynamic loads.

It must be emphasized the specification requirements were met during MA-6 and MA-8 inertia reel procurement. However, it has become evident that the specified performance requirements are inadequate to completely cover the crash environment we now are experiencing. Some of these crash environments are due to changes in operational tactics and others are due to advances in crashworthy helicopter designs.

MISHAP DATA

Aircraft mishap investigations generally focus on two questions: (1) what was the cause of the mishap, and (2) what can be done to prevent mishap reoccurrence? In view of these goals, inertia reel performance is a subordinate consideration. In the majority of U.S. Army rotary-wing mishaps, evidence of inertia reel failures does not exist. When evidence is present, often it is not reported because either the evidence is not recognized, or the occurrence is written off as an insignificant finding and not pursued. Part of this problem is related to insufficient instructions telling investigators what clues suggest a possible inertia reel failure.

Because of problems in identifying and coding inertia reel performance deficiencies, a typical search in the U.S. Army Safety Center database does not reveal significant findings. However, by conducting a search on injury types, and reviewing these accident cases for evidence of inertia reel failure, an alarming number of cases can be identified. This search identified 10 cases since 1983 in which the inertia reel can be attributed as faulty. Only survivable and partially survivable cases were considered. There were numerous nonsurvivable cases where the inertia reel performance could be suspect, but the severity of the crashes made secondary analyses unreliable. A short narrative of some of these cases and applicable investigation findings follow:

Case 1.

AH-64. Flying at about 70 knots and 400 feet AGL, a loud bang was heard and the pilot noticed a slight right yaw. As the yaw worsened, the pilot lowered the aircraft's nose to gain airspeed and streamline the aircraft. The aircraft continued to spin and the pilot entered an autorotation to reduce spin rate. The aircraft crashed in a wooded area and was destroyed. The aircraft burned during postcrash fire.

> "During the crash sequence, one pilot received fatal injuries and the other pilot serious injuries as a result of an inadequate crew restraint system. (A) The restraint system does not provide an automatic lock capability based on G forces other than longitudinally which allows excessive lateral body movements. (B) Excessive forces (2 to 3 Gs) are required to activate the system which leads to excessive body motion. (C) The manual lock levers on both crew seats are located in positions that interfere with the movement of the collective when a crew member has his hand on the lever."

Case 2.
OH-58. While conducting a zone reconnaissance at terrain flight altitude, pilot in command (PIC) executed an evasive maneuver, aircraft descended, main rotor blade struck several sand dunes causing loss of control and ground impact. The aircraft impacted the ground in a nose left side-low attitude. Aircraft was destroyed.

"The copilot sustained severe head injuries due to excessive flailing during the impact sequence."

Case 3.
AH-64. While at an out-of-ground effect hover, aircraft entered an uncontrollable right rotation about the mast and started descending. The IP attempted to execute a near vertical landing and impacted the ground at a high vertical rate of descent. Aircraft came to rest in an upright position with the empennage twisted and separated from the fuselage.

"The function of the shoulder harness locking lever on both seats is rendered inoperable during in-flight situations due to inaccessibility by either crewmember. The cockpit layout is inadequately designed because the locking lever is physically obstructed by the position of the collective and does not allow the crewmember to manually lock or unlock the shoulder harness restraint system. In this instance, the rated student pilot (RSP) received warning which would allow early locking of the harness but was unable to do so. During impact, he received a head injury when his helmet came into contact with the optical relay tube (ORT). This is a recurring finding on AH-64 accidents."

The IP's head struck the instrument panel resulting in a fatal basilar skull fracture. His other injuries were a small abrasion of the lateral right lower thigh, and a small contusion to both the left cheek and anterior left shoulder. The copilot/gunner received facial lacerations from striking the ORT.

Case 4.
UH-60. While in a hover attempting a night landing, aircraft struck a parked aircraft, lost tail rotor components and main rotor blade, then came to rest on its left side.

"During the crash sequence, the IP's upper torso restraint system did not lock in the automatic mode allowing excessive flailing. The system is designed to lock with X-axis (fore and aft) G forces; however the G forces encountered during this accident were primarily Y-axis (lateral)."

Case 5.
AH-1S. While in cruise flight, a loud bang was heard from aft section and pilot reduced power to reduce vibration. As the aircraft descended to about 10 to 15 feet AGL, it yawed right, rolled left, pitched down, and the left skid dug into the desert floor. The aircraft slid and rolled over 1 1/2 revolutions.

"The design of the shoulder harness locking device does not allow for activation 2 G's in the longitudinal axis, and no activation is incurred regardless of the amount of G's experienced in the lateral and vertical axis. The PIC's shoulder harness inertia reel did not activate at impact as evidenced by injuries sustained and also by a calculation of gravitational forces encountered at impact. As a result, fatal injuries were sustained by the PIC because his upper body was not adequately restrained in the seat and it was allowed to move within the cockpit during the crash sequence."

Case 6.
AH-64. During cruise flight at low altitudes utilizing night vision systems, aircraft began a gradual descent and contacted the ground at 85 knots true airspeed in a nose low attitude. The aircraft slid a short distance and rebounded into the air. The pilot activated the chop collar circuitry and the aircraft descended vertically, striking the ground and rotating 180 degrees after impact.

"The pilot's injuries were minor and consisted of abrasions and lacerations about his face and around his eyes." The copilot's "injuries were major and consisted of fractures to his right cheek bones, a fractured right mandible, and multiple abrasions about his face. Injuries were attributable to impact forces compounded by the ANVIS-6 goggles and his head striking the instrument panel."

CASE 7.
UH-60. While in a 20-foot hover, the aircraft tail rotor suddenly stopped turning. The aircraft began an immediate nose-down, violent right spin. The PIC applied power to transition to an open area and climbed to approximately 40 feet. At this point power was shut off and an autorotation initiated. The aircraft landed in a nosed-down, right roll attitude.

"The injuries received by the PIC and copilot were similar. As the seats were stroking down, the PIC struck his face on the collective and the copilot struck his face on the cyclic."

The causal factors for these facial injuries is attributed to the upper torso restraint system allowing excessive motion.

CASE 8.
AH-1. The main fuel and oil lines were severed by an OH-58 rotor blade, causing the AH-1 to immediately catch fire. The AH-1 continued straight ahead in a rapid descent. The AH-1 contacted two trees, struck the ground, rolled over, and burned.

"The front seat pilot was injured during the abrupt deceleration when his head and body moved forward, allowing his face to strike the TSU. The sight struck him just below his helmet at the visor line, inflicting extensive damage to his face and brain. He did not sustain any other injuries. ... It is suspected that his inertia reel did not function (lock) as designed, allowing his body to move forward and down, striking his face on the TSU, and inflicting injuries that caused his death 5 days later."

The pilot in the rear seat of this aircraft suffered a vertebrae compression and lacerations to his lower legs.

Case 9.
UH-1. After completing an airdrop, an internal (unauthorized) tarp broke free, impacted, and caused the tail rotor to separate. Descending, the aircraft started spinning to the right, leveled, stopped spinning, and struck the ground. The aircraft

impacted the ground in a right skid-low attitude with a slight right turn. Aircraft came to rest on its right side.

"The restraint systems were in place, intact, and in use at time of the mishap. However, the pilot's shoulder harness lock malfunctioned on forward impact. This malfunction caused him to receive a large cut across his nose and face from the cyclic handgrip."

The pilot was knocked unconscious for approximately 5 minutes and experienced amnesia retrograde. The causal factors for these injuries are attributed to the upper torso restraint system allowing excessive motion.

Case 10.

UH-60. Aircraft struck a power line causing the rotor system and tail rotor to separate from the aircraft. Aircraft began a rapid spin to the left and fell vertically 224 feet. The aircraft impacted in a left lateral, nose low attitude and was destroyed.

"The copilot sustained a severe blow to his head requiring 5 days hospitalization and an indefinite restriction from flying duty due to unconsciousness. The copilot struck his head on the cyclic grip with the helmet absorbing the majority of the impact."

LABORATORY TEST

Dr. Alem and his coworkers [2], U.S. Army Aeromedical Research Laboratory (USAARL), conducted a laboratory study on the effectiveness of airbags to reduce head injury severity from gunsight (optical relay tubes and telescopic sighting units) strikes in attack helicopters. As a part of this study, different inertia reel strap acceleration settings were used in an attempt to reduce total strap extension. Several MA-8 reels were set at the standard 1.5 - 3 G setting and others set between 1.2 - 1.8 G. Some new dual mode inertia reels, with a strap sensitivity setting of 1.2 - 1.8 G and a vehicle sensitivity setting of 4 - 5 G, also were used in some sled tests. The applicable inertia reel performance data reported in this effort are provided as Tables 1 and 2.

Table 1: Restraint system action and manikin interaction with the TSU in the AH-1 tests.

Test number	Sled pulse (G)	Seat back angle (deg)	Inertia reel		Amount of belt extension (cm)	Observations***
			Type	Lock setting (G)		
LX6196	19.6	5	MA-8	2-3	1.5*	No head contact.
LX6197	19.0	5	MA-8	1-2	3.0	No head contact.
LX6198	19.6	5	D.M.¶	1-2/4-5	6.5	No head contact.
LX6199	23.5	5	D.M.¶	1-2/4-5	2.0*	Minor helmet contact.
LX6200	23.4	5	MA-8	1-2	8.0	Minor head and helmet strike.
LX6201	23.4	5	MA-8	2-3	10.8	Minor face contact.
LX6202	25.0	35	**	**	**	Chin and cheek contact.
LX6203	25.0	35	D.M.¶	1-2/4-5	17.5	Nose and right cheek strike.
LX6204	25.0	35	MA-8	1-2	**	Full face impact.
LX6205	25.0	35	MA-8	Locked	3.5	Head and full face impact.
LX6206	25.0	35	MA-8	Locked	2.0	Head and right cheek strike.
LX6207	25.0	35	D.M.¶	Locked	11.0	Head and full face impact.

* Estimated from film analysis
** Data unavailable or clearly inaccurate
*** Based on review of high speed films and posttest photographs.
¶ Dual mode.

It is interesting to note the amount of belt extension allowed even with inertia reels in a prelocked condition. In test number LX6276, a prelocked dual mode reel allowed 11 cm of strap extension while two prelocked MA-8 tests (LX6274 and LX6275) allowed 3.5- and 2-cm strap extensions. The two MA-8 strap extension values can be attributed to webbing packing around the spool and strap elongation. But the dual mode's 11 cm strap extension is not easily attributed to packing and elongation. One possible explanation is the inadvertent unlocking caused by the crash pulse, i.e., the G force dislodged the locking pawl from the ratchet wheel and allowed additional extension to occur before reengagement.

With the reels in their automatic mode, the results are just as confusing. The MA-8 had recorded strap extensions up to 10.8 and 12 cm while the dual mode inertia reels recorded strap extensions up to 21.8 and 17.5 cm. Again, webbing packing and elongation must be taken into account, but do not totally account for these excessive strap extensions.

Analyses of the recorded strap displacements were inconclusive regarding the relative effectiveness of the different inertia reels and lock settings. However, these test results did verify inconsistencies within the MA-8 and the dual mode inertia reel's performance when subjected to a dynamic environment.

FAILURE MODES

As first reported by Schultz [3], there are two principal failure modes that are plausible. The first is a ratchet effect. Ratcheting occurs when the locking pawl, activated by strap acceleration, fails to properly engage the rotating sprocket. Figure 1 contains a sprocket and a locking pawl together. Two separate events are theorized to be able to cause this type of failure. The first event is random and is caused by an improper timing sequence between the locking pawl and sprocket. If the locking pawl initially contacts the tip of a sprocket tooth resulting in a partial engagement, the tooth or pawl may fracture from excessive shear loads. Fracturing

Table 2: Restraint system action and manikin interaction with the ORT in the AH-64 tests.

Test number	Sled pulse (G)	Seat back angle (deg)	Inertia reel		Amount of belt extension (cm)	Observations***
			Type	Lock setting (G)		
LX6208	7.7	35	D.M.¶	1-2/4-5	5.4*	Full face and forehead hit.
LX6209	6.7	35	MA-8	2-3	5.7*	Full face and chin impact.
LX6210	6.8	35	MA-8	1-2	7.0*	Full face and chin impact.
LX6211	6.8	35	D.M.¶	1-2/4-5	5.7	Chin and right face impact.
LX6212	6.8	35	MA-8	2-3	12.0	Lower face and chin impact.
LX6213	6.8	35	MA-8	1-2	5.7	Full face strike.
LX6277	8.9	35	D.M.¶	Locked	4.9	Full face impact.
LX6283	25.9	35	D.M.¶	1-2/4-5	21.8	Head impact with ORT.
LX6214	6.8	20	D.M.¶	1-2/4-5	4.5	Left forehead and mouth contacts.
LX6215	6.8	20	MA-8	2-3	4.5	Mouth and forehead contacts.
LX6216	6.8	5	MA-8	1-2	3.2*	Forehead and face impact.
LX6217	6.7	5	D.M.¶	1-2/4-5	**	Upper nose and forehead impact.

* Estimated from film analysis.
** Data unavailable or clearly inaccurate.
*** Based on review of high-speed films and posttest photographs.
¶ Dual mode.

either a sprocket tooth or the locking pawl would allow additional strap play out before the pawl reengages the sprocket.

The second event which may cause ratcheting occurs during high onset rates of strap acceleration. High onset rates usually occur during horizontal impacts. A finite amount of time is required for the locking pawl to move into the path of and then engage the sprocket teeth. During this period, the rotational velocity of the sprocket may be high enough that the pawl skips across the sprocket teeth instead of properly engaging them. This skipping would continue until the sprocket's rotational velocity slowed allowing the pawl to engage.

This type of failure is difficult to identify and verify because when motion finally ceases at full strap extension, the locking pawl engages the sprocket teeth and remains engaged during retraction. Inspection of the inertia reel at the accident scene reveals it to be locked, giving the misleading appearance that it functioned properly. Only through a detailed tear down inspection by knowledgeable personnel can this failure or a sprocket tooth chip failure be identified.

Figure 1. Inertia reel sprocket and locking pawl.

The second failure mode of the inertia reel is one where it fails to activate. This failure largely is dependent on crash kinematics. In the predominantly vertical helicopter crashes, the occupant's forward displacement rate and shoulder strap acceleration is insufficient to activate the inertia reel's locking sequence. This occurrence appears to be more prevalent with the newer crashworthy aircraft designs such as the UH-60 Black Hawk and AH-64 Apache. By design, crashworthy landing gear reduces the G onset rates and peak G forces transmitted to the occupants. This is complicated further by the occupant's initial response to vertical impacts which is to compress the seat cushion and torso slumping. The cumulative result is a gradual increase in shoulder strap acceleration and a delayed inertia reel activation. Since inertia reel activation is triggered by the occupant's shoulder strap acceleration, the occupant is exposed to an increased flail envelope and an increased risk of head and torso trauma.

USAARL FIELD TEST

Not all inertia reel failures can be attributed to changes in crash dynamics, but some responsibility must be placed on the reel's inability to maintain its calibration setting throughout its service life. CW4 Woodrum and his coworkers [4] raised the suspicion that the locking threshold of fielded inertia reels may not be within the required tolerance of 1.5 to 3 G strap acceleration. Mr. Woodrum contended that the lack of maintenance and calibration procedures fail to ensure that inertia reels continue to lock at the factory setting after prolonged exposure to field conditions. Based on this possibility, the Office of the Program Executive Officer, Aviation (PEO-Aviation) tasked USAARL to conduct a random sampling of inertia reels installed in various aircraft models located at Fort Rucker.

To accomplish this evaluation, a field portable inertia reel tester by Pacific Scientific, part number 3101101-0, was used for all tests. This tester is shown in a UH-60 copilot seat in Figure 2. The accuracy of the tester required that it be calibrated for each of the different seat configurations found in the various aircraft. Once calibrated, this device proved to produce a repeatable strap acceleration. The operation of this tester is mechanical and its energy is stored in a spinning fly wheel. The intent of this evaluation was to find what percentage of fielded inertia reels fail to lock at 3 G. Thus, the tester was set to provide 3 G strap accelerations.

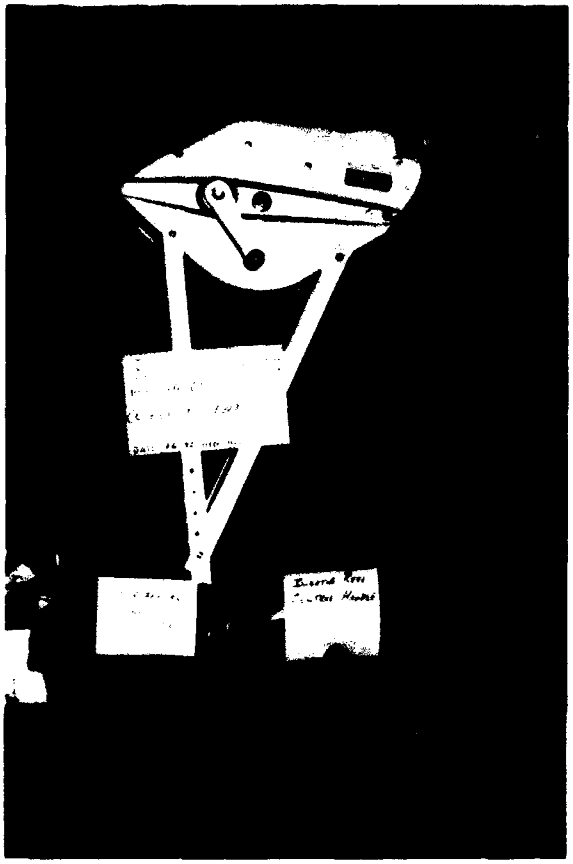

Figure 2. Pacific Scientific inertia reel tester shown in a UH-60 copilot seat.

Only the pilot and copilot inertia reels were tested in each aircraft. Aircraft models included the UH-1, AH-1, CH-47, OH-58, UH-60, and AH-64. A total of 55 aircraft were evaluated. The results of these field tests are shown in Table 3.

Table 3. Inertia reel locking failures.

Aircraft type	Reels tested	3 G failures	
		Number	Percent
UH-1	20	6	30
AH-1	16	10	62
CH-47	20	4	20
OH-58	14	4	29
UH-60	20	2	10
AH-64	20	1	5
Total	110	27	24.5

Based on the 110 inertia reels tested, 24.5 percent failed to meet the MIL-R-8236 limits and require recalibration. This is significant since it places the occupants of these inertia reels at an increased risk of head and upper torso injuries if involved in a mishap. The older aircraft models, UH-1 and AH-1, showed a higher failure rate than the newer, UH-60 and AH-64, models.

These data suggest that inertia reel sensitivity may be time and/or environment dependent. This dependency may be due to lubricant drying, material wear, spring fatigue, foreign matter, or other anomalies. Recording the manufacture date from the inertia reel label was not possible because of the inaccessibility of some reels. When reels were accessible, the labels were often unreadable.

Throughout MA-6 and MA-8 utilization, the service life has not been specified. Reels are replaced only if aviators or maintenance personnel find reels which do not lock when the shoulder strap is manually accelerated by hand or the reels fail to lock or unlock by the manual control handle. There are Army UH-1s, procured during the 1960s, still flying today with their original inertia reels installed. The performance levels of these reels remain highly suspect.

PROPOSED ACTIONS

There are several ongoing actions that are intended to relieve or correct the problems identified here. The first and most obvious is the adoption of maintenance and calibration procedures. PEO-Aviation has sent letters to inertia reel manufacturers asking for guidance and recommendations for maintenance and calibration procedures. Once this information is obtained and verified, it will be incorporated into the Army depot maintenance work requirement.

Another effort underway is a revision to MIL-R-8236. This revision includes a new inertia reel, the MA-14, which will be dynamically qualified. In this requirement, the inertia reel will be mounted onto a generic seat with a MIL-S-58095 [5] restraint harness and subjected to four different crash pulses. For each of these dynamic tests, the inertia reel must lock the shoulder harness within 1.9 cm (0.75 inch) of strap play out, not including webbing packing and elongation. Any measured webbing play out in excess of 1.9 cm (0.75 inch) will dictate failure of the reel to meet the requirement. Some designs being proposed include a vehicle sensitive G sensor and others include an increased sensitivity to strap accelerations with lower locking thresholds, or both.

For the AH-1 and AH-64 airframes, the Inflatable Body and Head Restraint System (IBAHRS) also is being developed. This system utilizes an aircraft-mounted G sensor to activate gas generators which inflate airbags integrated into the shoulder harnesses. This system has been under development for over 10 years and a production contract has been awarded. Introduction into service aircraft is planned for first quarter 1995, barring program delays.

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U.S. ARMY'S AVIATION LIFE SUPPORT EQUIPMENT RETRIEVAL PROGRAM REAL WORLD DESIGN SUCCESSES FROM PROACTIVE INVESTIGATION

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SUMMARY

The U.S. Army Aeromedical Research Laboratory (USAARL) manages the Aviation Life Support Retrieval Program (ALSERP). The purpose of this program is to evaluate and record the efficiency of Aviation Life Support Equipment (ALSE) in the aircraft accident environment with our focus centered on rotary-wing aviation. Personal injury data are correlated with the item of ALSE provided for protection, along with information on the accident kinematics and dynamics. These ALSE items are assessed for damage to determine if the design was adequate, it was manufactured to design, and/or it was properly worn by the crewmember. These data are used by USAARL to identify design deficiencies and to substantiate the need for system improvements. The ALSE sent to USAARL for analysis includes: helmets, crashworthy seats, restraint systems, inertia reels, survival vests, and flight suits from the U.S. Army, and upon request, the Navy, Air Force, Coast Guard, and other government agencies. The primary item of equipment received by USAARL for analysis remains the helmet due to the identified criticality of head trauma in aviation mishaps [1].

EARLY RESEARCH AND CONTRIBUTIONS

The U.S. Army established early credibility in research of trauma related to the aviation environment through several studies and subsequent reports. The first of these was published in 1961 by the U.S. Army Board for Aviation Accident Research (USABAAR) [1], Fort Rucker, Alabama. In this initial report, the USABAAR performed an analysis of accident data and found the U.S. Army had experienced 1214 major accidents from July 1957 through December 1960. These accidents were comprised of 571 fixed-wing and 643 rotary-wing aircraft. The study showed that 96.5 percent of the fixed-wing and 97.7 percent of the rotary-wing accidents were considered survivable. Although the survivability rate appeared to be quite satisfactory, a second analysis was conducted on fatal helicopter accidents from October 1957 through August 1959. Out of 24 fatal accidents, 11, or 46 percent, of these accidents were classified as survivable, yet 14 fatalities were experienced. At that time, survivability was narrowly defined as the limits of human tolerance related to crash forces. The author of this report attempted to provide further causative factors by surveying information on ALSE (Table 1) and found that nonuse of equipment due to either supply availability or personal selection played a significant role in survivability. Then, types of injuries were surveyed as the cause of death in survivable accidents (Table 2), showing the "big three" to be head injury, multiple extreme injury, and burns and complications. These three accounted for 77 percent of all injuries causing death. This report went on to discuss the aircraft inventory, postcrash fire experience, crash helmet experience, future injury patterns expected, etc. In short, it appears to be the first definitive self-examination of U.S. Army aviation survivability. The report prompted further inquires from the field on ALSE, crashworthiness, postcrash fire, and survivability. Also, it provided the aviation crewmember population with a proven reason to wear the APH-5 protective helmet which had not been totally accepted, even though it had been in the Army inventory since 1958 [2].

Table 1. Personnel in fatal survivable accidents.

Not using safety belt	3
Using safety belt	8
Unknown	3
Not using helmet	9
Using helmet	4
Unknown	1
Not using shoulder harness	12
Using shoulder harness	1
Unknown	1

Table 2. Type injuries as cause of death in survivable accidents, July 1957 - December 1960.

	F/W	R/W	Total
Head injuries	13	8	21
Multiple extreme	12	8	20
Burns and complications	8	8	16
Rupture or laceration of heart or great vessels	4	1	5
Hemorrhage and shock	0	3	3
Exposure -- cold, heat, etc.	2	0	2
Drowning	0	2	2
Traumatic hemothorax	0	1	1
Transection of spinal cord	1	0	1
Asphyxiation	1	0	1
Unknown	0	2	2

Until the publication of this first report, the aviation accident investigation teams of the U.S. Army had been diligently collecting, analyzing, recording data and identifying hazards from individual accidents with a selfless sincere dedication. The missing components of this endeavor were the cataloging, categorizing, and trend analyses that could make all of these data germane to the community which it served. Even today, we acknowledge there is adequate budget to investigate and identify the causes of specific accidents and sufficient command emphasis to complete the individual accident reports. According to the U.S. Army Safety Center (USASC), Fort Rucker, Alabama, an individual "Technical Report of U.S. Army Aircraft Accident" may contain multiples of 15 different forms with additional information as necessary, and total in the vicinity of 415 pages when completed. Basically, we still are structured to explain the loss, identify the hazards, and provide corrective measures to the responsible parties and command chain. However, there seems to be a continued lack of resources to complete the research necessary to identify trends within these data.

Under charter of The Surgeon General of the Army and the U.S. Army Medical Research and Development Command (USAMRDC), the U.S. Army Aeromedical Research Unit (USAARU) was formed to address aeromedical issues relating to Army aviation. Although the USAARU, redesignated USAARL in 1969, addressed a myriad of activities from noise exposure to human performance, when aviation accidents and survivability became issues of concern, the data reduction led to a narrowed focus in the arena of ALSE, and problems associated with the use of these items. One of the specific concerns within this narrowed scope was head injury and the protective helmet. USAARU continued to assess head trauma and took a proactive approach by presenting the results of research throughout the Army and by assessing not only what the U.S. Army had to offer, but surveying the other services and industry on what could be provided as protection to the aircrew. The Research Unit worked within the U.S. Army Qualitative Materiel Requirements (QMR), established for aircrew protective helmets in 1962, consisting of the following:

1. Compatibility with voice communication and attenuation against excessive noise.
2. Compatibility with integrated sun visor.
3. Flash blindness protection.
4. Oxygen and gas mask compatibility.
5. Ballistics protection.
6. Comfort.
7. Crash protection.

USAARU was not chartered to design a helmet, but unit personnel attended meetings with the Quartermaster Research and Engineering Center, Natick, Massachusetts, the U.S. Army Aviation Materiel Laboratories (USAAVLABS), Fort Eustis, Virginia, and met and corresponded with many others in the Government and private sectors pushing technology. In 1968, USAARU examined the U.S. Navy SPH-3 and found it to possess sufficient potential for the justification of exploring a new generation of flight helmets. The SPH-3 was modified to eliminate some stringent Navy specific protection requirements and strengthen some Army specific areas of concern. This USAARU-contracted helmet was designated the SPH-3X. It was compared to the existing APH-5 for acceptance and was found to be suitable [3]. After further study and additional design modifications, the proponent activity for helmets, the Quartermaster Research and Engineering Center, contracted and fielded this helmet. It was designated the U.S. Army Sound Protective Helmet No. 4, or the SPH-4, as it is known today. Although not part of the design push concerning helmet retention and crashworthiness driven by accident data, the USAARU acoustics section had been completing research and sending a strong message to the Army concerning noise exposure, hearing loss, and the risks associated with the aviation environment. The results were the significant improvements in acoustics protection included in this helmet. USAARU/USAARL succeeded in providing adequate justification for design changes through accident data, effectively researching sources of technology, and completing a concept evaluation to assist the materiel developer in selecting a product. One of the hidden, but most important, lessons of this effort realized after the fact was the willingness of USAARU/USAARL to turn over the true development program to the proponent activity and step back at the right moment. It is a lesson that serves us well today, in our capacity as a positive contributing resource to many development programs.

ESTABLISHING A PROGRAM

Perhaps the deciding factor in establishing a program to focus on aviation accidents and ALSE was due to the catalyst of two reports published in 1971. The first dealt with the costs of training, maintaining, and replacing an Army aviator [4], while the second covered injury and death costs in Army UH-1 accidents during a single fiscal year [5]. The economic reality of the hidden costs associated with accidents is a tangible fact that can transcend the uncertain payback often associated with research. In 1972, USAARL established the Aviation Life Support Equipment Retrieval Program (ALSERP). The program was defined in the then Army Regulation 95-5, "Aircraft accident prevention, investigation and reporting" [6]. The ALSERP was established with regulatory authority necessary for acceptance by the Army in the field. Regulation titles have changed, but ALSERP maintains its authority today in Department of the Army Pamphlet (DA Pam) 385-95, "Safety, aircraft accident investigation and reporting" [7]. In addition, USAARL has the unique freedom to move within the safety channels by Letter of Agreement with the USASC. We benefit greatly from USASC investigator contributions and in obtaining detailed information and material from mishaps. In 1979, Memoranda of Agreement were signed with the U.S. Navy Aerospace Medical Research Laboratory, Pensacola, Florida, and the U.S. Air Force Inspection and Safety Center, Kelly Air Force Base, Texas, for the submission of crash damaged helmets to USAARL for analysis and with the aim of forming a triservice database on aviation crewmember helmet performance.

The ALSERP program may have been founded on our ability to perform accident record analyses, but USABAAR, and later the USAARU/USAARL, realized that physical examination of the actual ALSE involved in the accident was necessary. Not only did physical laboratory-based examination of an accident helmet allow a more detailed analysis by a selected team of experts, it also provided the actual item for accurate duplication of damage or impacts in the laboratory, if desired. Initially, field units were enthusiastic about sending crash-damaged helmets and other equipment to USAARL for analysis, but the accountability of equipment and supply replacement became a factor. Today, DA Pam 385-95 includes a chapter on personal protective equipment stating that all ALSE which is suspect of being linked with the cause or prevention of injury during a mishap is to be sent to the USAARL for analysis. Further, it provides the unit commander with procedures for the turn-in and accountability of equipment sent to the ALSERP. Even with this direction, it is understandably difficult for unit commanders to send away and write off selected helmets worth over $9,000 that may or may not be damaged. Education about the requirements and purpose of the program and open lines of communication between USAARL, the USASC, and the field units are necessary to guarantee both the integrity of the investigation and preservation of limited unit assets. Again, regulatory guidance is necessary for a functioning program.

NARROWING THE SCOPE OF THE EFFORT

The intense interest of the ALSERP project officers may be shared and taken to the field by accident investigators. Results sometimes take the form of boxes containing miscellaneous equipment taken from an accident scene that may or may not have anything to do with the survivability issues at hand. Worse yet is the well-intentioned new investigator who sends all of this material with little or no labeling or notes on what parts came from where. The ALSERP has addressed these problems by defining parameters for collection to guide the field investigator. In the case of the helmet, we limit retrieval to helmets involved in accidents in which any one of the following events has occurred during the accident sequence:

1. Helmet damage:
    a. Fracture, puncture, crack, gouge, or delamination of the outer shell.
    b. Failure or tear of the chinstrap, nape strap, or retention assemblies that would otherwise necessitate repair to the helmet before reissue.
    c. Visible damage to the energy-absorbing inner liner.
2. Wearer injury:
    a. Wearer becomes concussed (impaired consciousness).
    b. Wearer receives any type of major head or neck injury.
    c. Major injuries are defined as injury involving:
        (1) Five days of hospitalization.
        (2) Unconsciousness due to head trauma.
        (3) Fracture (open or closed) of any bone, including the nasal bone.
    d. Moderate to severe lacerations which cause extensive hemorrhage or require extensive surgical repair [8].

We request that investigators do not adjust or disassemble helmets when they are retrieved. We also ask investigators to call if there is <u>any</u> question regarding the retrieval of a helmet. For instance, it is possible that significant crash forces were present in a specific mishap and the helmet shows signs of multiple impacts but does not meet the parameters of damage and the wearer was not within the injury patterns listed above. We would ask the investigator to have the unit ALSE technician remove the inner styrofoam liner and check for damage. Although no external cosmetic damage is present to the outer shell, unit ALSE personnel have removed the inner styrofoam liners and found compression of the liner on the surface interfacing the shell or a delamination of the shell on the inside, or both.

Other equipment may be sent to the ALSERP depending on the issues involved or according to the interest of any of the Aviation Accident Board members. Any crashworthy seat involved in an accident where injury is sustained or any seat that shows signs of stroking due to impact forces automatically is sent to the ALSERP. Oftentimes, all equipment worn by a deceased crewmember is collected and sent to the program, although this is not a requirement.

MEDICAL INFORMATION

Medical information derived from accident reports may come in the manner of computerized cataloging of data under coded text or the actual medical report or autopsy. Although the coded "check the box" format greatly reduces the workload of the flight surgeon on the Accident Board, codifying information greatly reduces the detail in the description of injury. This is true, especially for cases with multiple injuries on one individual and limited spaces or descriptors on the preprinted form. For the sake of brevity, small contusions and abrasions may not be included. In attempting to explore and possibly establish relationships between the injury and the helmet damage, these overlooked data are critical. For the purpose of ALSERP, we request a copy of the actual medical report or autopsy in its entirety.

This program needed a standard measure for the classification of injury that would be of utility to a wider population than just the U.S. Army. The 1976 Abbreviated Injury Scale (AIS) [9] published by the American Association for Automotive Medicine was selected as the foundation for cataloging ALSERP injury data. This first AIS provided a single overall AIS value assigned to each patient on the basis of the expertise of the medical personnel in attendance. The 1980 revision did not support this method of overall evaluation and recommended several alternative methods of assessment. The most useful for our program is the maximum AIS (MAIS) which uses the highest AIS number assigned to any single injury of the patient to characterize the overall severity. For use in helmet analysis, injuries other than to the head and neck may provide a misleading descriptor in establishing relationships of injury and protective performance. For instance, the AIS limited to the combination of head, neck, external, and the upper vertebrae of the spine may be used for a helmet or head injury-related issue. Conversely, the MAIS should be used when addressing airframe crashworthiness and crewmember flail injury. Continuity of reporting assessments is not possible when one report is published under one standard and the AIS is modified, but the program is set up to use the current AIS for comparison with previously collected data. As of this writing, the 1980 AIS is the latest revision that has been used for reports in this program, although the 1988 AIS will be used for subsequent reports. An example of 1980 AIS codes for head injury is presented in Table 3.

FORMAT FOR HELMET ANALYSIS

The following is an explanation of the ALSERP helmet review form. It is presented in its work sheet format in Appendix A. The intent is to provide the reader with the outline of an approach to ALSE investigation and injury correlation. The flow starts with demographics of the mishap (blocks 1 and 2), the aircraft (block 3), the wearer (blocks 4-6), and the helmet (blocks 7-9). It continues with the wearer's position in the aircraft (blocks 10 and 11) and the injuries incurred (blocks 12-14), including the issues of possible modifications to improve performance of the helmet (blocks 15 and 16). AIS codes are provided in blocks 17-26, followed by helmet retention and earcup issues (blocks 27-30). Visor issues are listed in blocks 31 and 32 and correlated to insult possibly caused by the visor (blocks 33-36). Helmet rotation is covered in block 37. The clip damage referred to in blocks 38-43 is an issue relating to the sling suspension of the SPH-4 only. Block 44 identifies disposition of the helmet for further assessment. Helmet shell damage is covered in blocks 45-62. The compressible inner liner and damage to it are covered in blocks 63-69. Based on the SPH-4 sling suspension system, this form does not allow for assessment of the dimpled plastic sheets or cover of the thermoplastic liner (TPL™) or the inner basket assembly and internal electronic "can" assemblies of

Table 3. A sample of 1980 abbreviated injury scale (AIS) codes*.

0	No injury	
1	Minor	No unconsciousness; nasal fracture, superficial scalp lacerations, dizziness, headache
2	Moderate	< or = 15 min. unconscious; linear fracture, inner ear injury orbit fracture, retinal detachment, deep scalp laceration, Le Fort I Maxillary fracture
3	Serious	15-59 min. unconscious; eye avulsion, Le Fort II maxillary fracture, ethmoid fracture
4	Severe	1-24 hrs. unconscious; Le Fort III maxillary fracture, epidural or subdural hematoma < or = 100cc; life threatening
5	Critical	>24 hrs unconscious; epidural or subdural hematoma > 100 cc; survival uncertain
6	Maximum	Currently untreatable, partial or complete decapitation, crushed skull
9	Unknown	Insufficient clinical or pathological information

* The Abbreviated Injury Scale 1980 Revision.

the Apache Integrated Helmet and Display Sighting System (IHADSS). Currently, we do not have enough accident experience with the IHADSS or the TPL™ to adequately set a catalog system of data assessment.

THE LABORATORY REVIEW TEAM

When considering the laboratory analysis, the composition of the ALSERP inspection team is a critical element. USAARL uses a minimum team from the selected disciplines of ALSE, medicine, engineering, aviation, and safety. The ALSE technician is current and versed on the equipment being analyzed. The flight surgeon is active and on flight status representing the specific military service involved in the accident. The design engineer may be an aerospace or general engineer with experience in the specific item being analyzed. The pilot is an instructor pilot currently on flight status and preferably qualified in the specific aircraft type, model, design, and series involved in the accident. The safety specialist is performing the safety officer's function as a primary duty and has experience in aircraft accident investigation. Any member of the team may be performing dual functions such as an aviation safety officer who is also a unit instructor pilot, or an aerospace engineer who also is performing the duties of an ALSE technician. Additional expertise is drawn from the U.S. Armed Forces Institute of Pathology (AFIP), Washington, D.C., the USASC and its field investigators, Natick Laboratories, Program Managers' offices for various aircraft and subsystems, etc., as necessary. No case review is accomplished without the presence of all necessary parties defined above. In reality, this requirement often is difficult to comply with in a timely manner due to the varied primary duty responsibilities of those involved, but participation by all parties eliminates questions at a later date and, therefore, this procedure is not compromised.

PROGRAM SUCCESSES

Since 1972, USAARL has received and reviewed over 340 helmets, 100 seats, and numerous restraint systems, including varied items such as survival vests and articles of flight clothing. The results of the assessments of these items have provided the initial focus for further research in different paths of study. Human head and neck response to impact acceleration and head injury pathology coupled to the clinical, safety, and administrative significance of these issues have been explored. We have published reports on helmet damage and head injury correlation that cite head injury at peak acceleration levels far below the 400 G used for the manufacturing performance criterion in Army helmets [10] at that time. Subsequently, we again pushed technology and we have moved the drop height from 3 feet with a peak of 400 G to a drop height of 6 feet and set a 150 G (never to exceed) peak acceleration requirement which is being met. Two reports have covered the SPH-4 helmet performance. One covered the period 1972-1983 [11] and the second covered the period 1983-1987 [12].

USAARL again entered the concept evaluation field in 1982 over the concern of transmitted loads to the head from lateral impacts in the helmet earcup area. Designed for sound attenuation, the standard SPH-4 earcup reached a compressive force of up to 5000 pounds prior to fracture which was well beyond human tolerance. USAARL contracted for the manufacture of a crushable earcup that also would meet the acoustic protection requirements of the Army. The metal crushable earcup produced proved satisfactory on both counts [13]. Again, we were faced with the proven versus accepted issue and the ALSERP program "finished the job" by performing a study and publishing a report on lateral impact to the head [14]. We reviewed aircraft accident case files between 1971 and 1979 covering 222 flight helmets and found clearly that lateral impacts yielded a higher rate of serious injury to the head than other areas of impact (AIS greater than 4) at a 68 versus 46 percent incidence. Similarly, there was a greater incidence of basilar skull fracture due to lateral impacts than to other areas of the helmet (46 versus 18 percent). We established the proven "blood priority" of basilar skull fracture and again offered a concept, the crushable earcup, from the survivability standpoint. The Army looked with intent to move on this issue. Today, contractors are successfully manufacturing crushable earcups of ABS plastic. Various types have been included in the SPH-4B and the HGU-56/P. Crushable earcups are one of the basic design requirements for all future Army aviation helmet systems.

When helmet-mounted sight systems were added to our aircraft, we assessed the affect of vibration on the sight using mechanical linkages [15]. In 1981, we completed a variable weight center-of-gravity (CG) helmet simulator for assessing helmet-mounted devices and the affect on muscle loading and fatigue on our aviation crewmember population [16]. The results of these studies have been used in the criteria for the development of helmet sight technologies currently being considered for the RAH-66 Comanche.

We have shared our concern over the aviation crewmember protective helmet with studies involving bump protection requirements of the armored vehicle crewman's helmet. We have studied injury patterns and provided guidance to the U.S. Army Airborne School, Fort Benning, Georgia, the XVIII Airborne Corps, Fort Bragg, North Carolina, and Natick Laboratories relating to head injuries and protective alternatives for airborne training and operations.

In 1982, we published the "Analysis of U.S. Army Aviation Mishap Injury Patterns" [17] which included examples of injury data use by program managers, resulting in improvement programs being incorporated into Army aviation.

Seat belts and inertia reel systems also have been a primary area of interest in the ALSERP program. USAARL has been instrumental in tightening requirements on seat belt elongation due to our experience investigating accidents involving head and face strikes on optical tracking devices in our attack helicopters. When shoulder harness lead-in strap failures began to occur in one aircraft type, timely ALSERP participation identified an incorrect installation of the seat belt guide [18]. The corrective action was an immediate grounding of all aircraft and a one-time inspection for and correction of this deficiency.

During the design and fielding of the AH-64 Apache helicopter, scientists and engineers from USAARL and the ALSERP participated by Army charter and not always by invitation of the program manager. The IHADSS was developed by the manufacturer with limited input from the Army other than basic global design requirements and goals. One example of the program direction is that in the development phase, the contractor was using a poured foam-type liner which USAARL identified as a component that failed to meet impact standards. The use of this liner was continued throughout development because of its superior stability attributes, especially since helmet stability was a recognized critical factor in helmet-mounted sighting issues. Our engineers often were perceived as a thorn in the side throughout development. Only when the Apache was ready to be fielded and initial key personnel training commenced did the contractor come out with the true proposed liner. We impact tested the helmet with the new liner design and it passed with only minor problems. However, we did identify fitting problems with this liner, both in the lengthy 2.5-hour fitting process and the requirements for multiple subsequent fittings to relieve hot spots experienced by the pilots. Both the contractor and the program manager denied difficulty in this process and stated the Army had no experience in the complexity of such an advanced system. Fitting was officially declared satisfactory.

USAARL volunteered its services to become the first U.S. Army helmet fitters. The ALSERP laboratory became the initial fitting station for the AH-64 transition course and also became the contact point for helmet materiel problems relating to the IHADSS [19]. During the fielding of the AH-64 at Fort Rucker, USAARL was fitting two sessions of pilot classes once a week and noted the continued problems in fitting this population with the size regular or large IHADSS. First, we assessed the helmet and found that it had, indeed, been manufactured to the specification. Then, we assessed the pilot population and found the 1970 anthropometric data used for the specification did not reflect the pilot population entering the AH-64 training program. USAARL then funded a worldwide survey of all attack pilots in the Army and found the head anthropometry of these pilots was close to a full centimeter larger in the 99th percentiles of the 1970 data identified in the specification. Further, the M-43 protective mask was designated as the protective mask of the Apache program and it had to fit the pilot's head under the helmet which added a new delta to the head dimensions. The study showed that 9.6 percent of the population would have difficulty fitting the IHADSS alone, and 29.5 percent of the pilot population would have difficulty fitting into the IHADSS while wearing the M-43 protective mask [20]. USAARL completed the research and provided the criteria for the extra-large IHADSS helmet currently in service.

Participation in the AH-64 program continues through the ALSERP. A fatal mishap in January 1992 revealed a possible design flaw in an overhead circuit breaker panel. Although not a contributing factor in the fatality, the undesirable frangibility of this overhead panel was noted as a failure for the third time out of three AH-64 accidents by the ALSERP investigators at the accident site. The possibility of this panel causing injury clearly is present. ALSERP has forwarded information on this hazard to the program manager's office and action officers are including this issue in the next System Safety Working Group where redesign of the connection points will be directed. Clearly this is not an ALSE issue, but it was explored due to its possible interface with the helmet worn by the crewmember.

The Army's latest effort is the development of the Light Helicopter Experimental (LHX), later designated the RAH-66 Comanche helicopter. This aircraft is designed to fulfill the missions of scout and light attack. Unlike the Apache program, USAARL participation in the Statement of Work, the setting of program requirements, and the Source Selection Board were not only actively sought, but have been and continue to be funded by the Comanche program manager. USAARL provided criteria in the form of a report defining health hazard issues in the helmet integrated display and sighting system (HIDSS) for the LHX [21]. This report was used by the competing teams in the conceptual development of their respective candidate helmet technologies. Innovative approaches to headborne visionics and head protection were explored and presented by the competitors. USAARL responded by considering these new approaches and modified the Army's requirements to address and allow exploration and development of these new concepts and devices. The "Revision for the Health Hazard Issues in the Helmet Integrated Display and Sighting System (HIDSS) for the Light Helicopter Experimental (LHX)" [22] was published in September 1988 and allowed contractors to benefit from their exploration. As of March 1992, major issues of concern in the helmet arena for this program remain the visionics, crashworthiness, acoustics, helmet retention, and protective visors. USAARL and ALSERP team members currently are full members of the Crew Station, Helmet, Airframe, MANPRINT, and System Safety Working Groups of the program.

CONCLUSIONS

The investigation and identification of cause factors in aviation accidents are only the first steps in providing what should be expected from a safety assessment. The presentation of clear injury data used to substantiate design improvements and the exploration of design alternative concepts should be the goal of each program. The ALSERP strives to meet these goals throughout the ALSE spectrum. Cost benefit analysis provides the basis for crashworthiness improvements and has led to design "firsts" in crashworthy seating, aircraft/airframe crashworthiness, new requirements in head protection, human anthropometric design requirements for optimized performance and survivability, inertia reel and seat restraint system direction, and considerations for helmet design relating to stability required for helmet-mounted displays. Frangibility of aircraft structure and the associated mechanical insult now are included in the systems approach to cockpit design due to accurate substantiated health hazard identification. Regulatory authority to retrieve material matched with a tested process of data collection and the required membership of varied disciplines in the investigation guarantee the overall program success and validity. The unsolicited request for assistance by the program office responsible for the development of the next generation of U.S. Army Helicopter, the RAH-66 Comanche, illustrates the maturity and the utility of this program to our target audience, U.S. Army aviation.

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APPENDIX A.

ALSERP Helmet Review Form

1. USAARL case no. ______
2. USASC case no. ______
3. Aircraft type ______
4. Last name of wearer ______
5. SSN ______
6. Wearer's age ______
7. Helmet type ______
8. Helmet manufacturer ______
9. Helmet contract no. ______
10. P ition of wearer in aircraft at time of impact:

    Pilot ______ copilot ______

    Passenger: left ______ middle ______ right ______
11. Seat orientation (facing): forward ______ side ______

    rear ______
12. Was this accident fatal to the helmet wearer? Yes ______ no ______
13. Were head, neck, or facial injuries present? Yes ______ no ______
14. Was the primary cause of death a head, neck, or facial injury?

    Yes ______ no ______
15. Might a future operationally feasible design or material modification to the helmet likely prevent the most serious injuries? (i.e., so that fatal cases might become nonfatal and nonfatal cases might have their MAIS code reduced by one or more)

    Yes ______ no ______
16. What operationally feasible modification to the helmet would be recommended by the inspection team?

    ______

List of head, neck, and face injuries:

17. #1- ICD code: AIS code:
18. #2- ICD code: AIS code:
19. #3- ICD code: AIS code:
20. #4- ICD code: AIS code:
21. #5- ICD code: AIS code:
22. #6- ICD code: AIS code:
23. #7- ICD code: AIS code:
24. #8- ICD code: AIS code:
25. #9- ICD code: AIS code:
26. Head, neck, face maximum abbreviated injury scale (MAIS) ______
27. Did the helmet come off the wearer's head?

    Yes ______ no ______ Unknown ______
28. Chinstrap failure? Yes ______ no ______
29. Retention system attachment point failure? Yes ______ no ______
30. Earcup damage? Yes ______ no ______
31. Visor position at impact.

    Up ______ down ______ unknown ______ N.V.G. ______
32. Was visor broken? Yes ______ no ______

List injuries caused by broken visor:

33. #1- ICD code: AIS code:
34. #2- ICD code: AIS code:
35. #3- ICD code: AIS code:
36. #4- ICD code: AIS code:
37. Did helmet rotate and expose head to injury? Yes ______ no ______

Clip damage (look down into helmet):

1=No deformation
2=Slight deformation
3=Moderate deformation
4=Severe deformation

38. Left front ______
39. Front ______
40. Right front ______
41. Right rear ______
42. Rear ______
43. Left rear ______
44. Helmet available? Yes ______ no ______

Impact surface information:

	Impact no.	Concave (1)	Flat (2)	Wedge (3)	Box corner (4)	Hemisphere (5)	Rod (6)	Unknown (7)	Impact angle (8)	Object struck (9)
45.	___	___	___	___	___	___	___	___	___	___
46.	___	___	___	___	___	___	___	___	___	___
47.	___	___	___	___	___	___	___	___	___	___
48.	___	___	___	___	___	___	___	___	___	___
49.	___	___	___	___	___	___	___	___	___	___

50. Were there any impac to the helmet? Yes ______ no ______

Impact location: (Impact no. and damage code in appropriate blank)

D=delamination F=fracture P=puncture MM=material missing
G=gouge A=significant abrasion 4mm ND=no damage

51. Crown: Front ___
52. Left side ___
53. Right side ___
54. Rear ___
55. Front: Left ___
56. Right ___
57. Left side: Front ___
58. Rear ___
59. Right side: Front ___
60. Rear ___
61. Rear: Left ___
62. Right ___
63. Uncompressed thickness of foam liner: ___ cm.

Permanent foam compression:

	Impact No.	Major axis (cm)	Minor axis (cm)	Area (cm^2)	Percent compression at greatest point
64.	___	___	___	___	______
65.	___	___	___	___	______
66.	___	___	___	___	______
67.	___	___	___	___	______
68.	___	___	___	___	______

69. Impact simulation possible? Yes ___ no ___

Remarks:

THE EFFECTIVENESS OF AIRBAGS IN REDUCING THE SEVERITY OF HEAD INJURY FROM GUNSIGHT STRIKES IN ATTACK HELICOPTERS

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1. SUMMARY
Accident investigation records at the U.S. Army Safety Center were examined to determine the frequency of gunner injuries incurred from striking the optical sighting systems in the Cobra and Apache attack helicopters during survivable mishaps. Among 105 survivable Cobra crashes during 1972-1990, the sighting system was implicated in 9 minor and 5 major injury cases, and 6 fatalities The Apache had eigh survivable mishaps since 1985, with only one gunner fatality which was attributed to the optical relay tube (ORT). In this Apache mishap and in the 11 Cobra cases where major or fatal injuries occurred, we theorized an airbag would have prevented serious injuries.

To explore the role of airbags in reducing the severity of head strikes, we conducted 32 sled tests with and without airbags. In all tests without airbags, head strikes of the test manikin were sufficiently severe to cause facial fractures, but not necessarily irreversible brain damage. Airbags proved effective in reducing the severity of head strikes against sighting systems. Using mean values of several indicators of injury severity, airbags reduced head accelerations by 65 percent, head injury criteria by 77 percent, and head angular acceleration peak-to-peak swings by 76 percent in the Cobra tests. In the Apache tests, the airbags reduced those same indicators by 68, 52, and 83 percent, respectively. The study concludes that an airbag system, specifically designed for the Apache or Cobra, likely would prevent severe or fatal head and chest injuries.

2. INTRODUCTION
The U.S. Army first introduced the AH-1 Cobra into combat service in 1967 to serve as an attack and antiarmor helicopter. Since then, the Cobra received a number of upgrades to improve its performance and weapons capability. In 1985, the Army fielded the AH-64 Apache as a new generation attack helicopter offering marked improvements in performance and armaments, and an ability to operate at night and in poor weather conditions. Both the Cobra and Apache are attack helicopters designed to operate in a high threat environment. Even in peacetime, the training missions for these aircraft subject their pilots to high risks of injury.

A common feature of both aircraft is the presence of a gunsight in the front cockpit used for target sighting, ranging, and designation of the tube-launched, optically tracked, wire-guided (TOW) or Hellfire missiles. In the Cobra, the gunsight is referred to as a telescopic sighting unit (TSU) and in the Apache, it is an optical relay tube (ORT). From a crash injury viewpoint, the Apache ORT differs significantly from its counterpart in the Cobra in two areas: Its proximity to the gunner and its breakaway design, a feature that allows it to yield to excessive forces generated by the striking of the crewmember's body during a crash. Because of the presence of the sighting systems, the copilot/gunner in both types of helicopter can sustain serious or fatal injuries if his upper body strikes the gunsight during a crash. Of particular concern is the potential for serious head injury from head strikes on the TSU or ORT.

In this paper, we present the results of a study in which we addressed several aspects of the problem of head strike with the sighting system: (a) Accident investigation data of the U.S. Army Cobra and Apache mishaps in which the sighting systems were implicated in the gunner's injuries, (b) movement of the gunner's helmeted head relative to the sighting systems during simulated Cobra and Apache crashes, (c) effectiveness of inertia reels and restraint systems to prevent head strikes, and (d) usefulness of rapidly inflating air cushions in reducing the severity of head strikes on the gunsight system during crashes.

3. ACCIDENT AND INJURY DATA
Many investigators have documented injuries occurring in U.S. Army helicopter crashes in numerous studies over the past 25 years [1-7]. The studies suggest that most survivable helicopter crashes involve near vertical impacts with terrain, and most injuries arise from forces generated along the vertical axis. Consequently, design standards for crash resistant helicopters emphasize reducing crash forces along the helicopter's vertical axis. Current U.S. Army design standards require forces to remain within tolerable limits at all occupiable positions for vertical impacts of up to 12.8 m/s on a hard surface [8].

Human tolerance to vertical acceleration generally is accepted to be limited to 20-25 g (1 g = 9.80665 m/s^2) for approximately 100 ms. Because little or no crushable structure exists on the bottom of standard fuselages and because of the unpredictability of most impacted surfaces, design standards require energy attenuating capability be provided in the landing gear, fuselage floor, aircraft seating, or any combination of the three. Both the Apache and UH-60 Black Hawk helicopters incorporate energy-absorbing landing gear and stroking seats. As we will discuss below, the addition of these features modifies the crash pulse of these helicopters in comparison to other noncrashworthy helicopters.

Energy-absorbing features have performed extremely well in both the Apache and the Black Hawk since impacts at vertical velocities in excess of 12.8 m/s have been survivable in both helicopters. Nevertheless, significant number of injuries still occur in survivable crashes of these helicopters. A recent review of injuries sustained in Army helicopter crashes demonstrated injuries due to excessive acceleration are, in fact, reduced in Apache and Black Hawk crashes compared to other helicopters [7]. We should note that contact injuries in all helicopters outnumbered acceleration injuries by a ratio of approximately five to one. Contact injuries are produced by secondary collisions that occur when an individual strikes or is struck by an object. These contact injuries are caused by inadequate restraint, collapsing structure, or a combination of both mechanisms.

To document the frequency of injuries resulting from TSU or ORT strikes, we reviewed accident records of the Cobra and Apache at the U.S. Army Safety Center (USASC). These include all survivable ground impact Cobra mishaps from 1 January 1972 to 30 June 1990. During this period, 105 Cobra crashes were classified as survivable or partially survivable with a nonzero vertical velocity at terrain impact. Of these crashes, 20 (19 percent) resulted in injury to the copilot/gunner as a result of striking the TSU. Six individuals (6 percent of all crashes) received fatal injuries, another five received major injuries, and nine received minor injuries.

In the six fatal Cobra crashes, the gunner who sits in the front seat died as a result of striking the TSU (five head strikes and one chest impact), whereas the pilot, who sits in the rear seat away from the TSU, sustained relatively minor injuries. Even though the accident reports suggested two of the six individuals failed to properly tighten their upper torso harnesses, we concluded the fatalities would not have occurred in the absence of the TSU. In all accidents resulting in major or fatal injuries from striking the TSU (a total of 11), we felt an airbag system would have prevented serious injury.

In crashes resulting in major injury from TSU strikes, the mean longitudinal velocity at impact was more than twice that of those that did not involve TSU strikes: 20.6 m/s versus 8.72 m/s. All fatal injuries occurred at impact longitudinal velocities over 10.3 m/s except for one case of 2.1 m/s where the individual reportedly failed to tighten his upper torso restraint. Furthermore, only one chest/head injury occurred at a longitudinal impact velocity of less than 5.2 m/s, except for the one case described above. When we compared vertical velocities at ground impact for those accidents resulting in major or fatal injury to those from other Cobra accidents, we found no significant difference (student T-test, $p > .05$) between the two groups: 5.33 m/s versus 3.47 m/s. These findings suggest TSU strike injuries, unlike most helicopter crash injuries, are relatively independent of the vertical velocity at impact and highly dependent on longitudinal velocity.

We also reviewed mishap records of the Apache covering the period since its fielding in 1985 to 30 June 1990 and found there were eight survivable ground impact mishaps. Of these, only one resulted in injury to the copilot/gunner as a result of striking the ORT. In this case, the crewmember received a concussion and facial fractures, and the estimated vertical and longitudinal velocities at impact were 9.44 and 2.56 m/s, respectively. Also, there was a nonsurvivable crash of an Apache where the copilot/gunner sustained a forehead laceration when he struck the ORT. The estimated vertical and longitudinal velocities at impact in that case were 15.5 and 1.1 m/s, respectively.

Although the crash experience with the Apache has been limited, the ORT clearly presents a significant hazard to the front seat occupant in spite of its breakaway design. Furthermore, the combination of energy-attenuating landing gear and a stroking seat in this helicopter, and the closer proximity of the ORT compared to the TSU, makes contact with the ORT less dependent on longitudinal velocity than in the case of the Cobra. If this hypothesis is correct, we can anticipate a higher rate of gunsight strikes in the Apache than we have experienced in the Cobra.

An additional factor to consider is in the Apache: The impact energy-attenuating design of the airframe modifies the impact forces so the impact duration is longer. The longer duration results in slower torso motion that may not generate the 2 to 3 g upper torso acceleration required to activate the lock on the shoulder harness inertia reels in time to prevent a head strike on the ORT. Therefore, the standard 2 to 3 g setting of the shoulder harness inertia reel may not provide the appropriate and intended level of protection for the front seat occupants in the Apache.

One remedy to the head strike problem would be to adjust the shoulder harness inertia reel in order to activate its locking mechanism earlier in the impact sequence, thus reducing the forward movement of the torso and head. Another would be to install a rapidly inflating air cushion placed between the head and the sighting system and tailored so as not to interfere with the normal operation of the controls. The airbag can be deployed rapidly by means of a sensor and diagnostic system sensing the impact accelerations of the aircraft striking the ground.

4. MATERIALS & METHODS

We conducted tests for this study in two phases: The first in October 1988, and the second in October-November 1989. The tests were conducted at the Naval Biodynamics Laboratory (NBDL) using a horizontal linear accelerator sled to simulate the desired crashes.

4.1 Cockpit Hardware

To perform multiple impact tests and observe the interaction of the test subject in the front seat environment of the Cobra and Apache, we fabricated test devices using a combination of actual aircraft hardware and an adjustable support structure. The aircraft hardware used for the Cobra tests included the distal section of the TSU, the Cobra restraint system with the inertia reel, and the Cobra armored seat and bottom seat cushion. We also included the back seat cushion in the test structure.

The cockpit support structure was designed to permit quick reconfiguration of test hardware and modifications of the impact parameters. The structure included a hinge at one end to allow for different pitch orientations. On horizontal sleds such as the one used at NBDL for this project, vertical impacts are simulated by placing the seated subject with the seat back nearly parallel to the horizontal tracks. Since the manikin longitudinal spinal axis is laid along the seat back, the direction of the impact vector relative to the spine is equal to the angle between the seat back and the sled tracks.

An overall view of the setup for tests with the Cobra and TSU is shown in Figure 1. The hardware used in the Apache tests included the full Apache energy-absorbing crew seat and seat cushions, the Apache restraint system with the inertia reel, and the distal direct viewing section of the ORT. The bottom section of the ORT that contains the ORT control box and a CRT were simulated using a specially fabricated box with lead weights to duplicate the actual structural weight. An overall view of the Apache test setup is shown in Figure 2 with the ORT installed in the front portion of the test fixture.

The mount of the ORT was designed to collapse when the impact force exceeded 400 pounds. To retain the frangibility of the ORT in the test fixture while providing a reusable test apparatus, the original mounting bolts that held the upper portion of the relay tube to its base were substituted with nylon screws selected to fail in shear and to be easily replaced. The 400-lb collapse threshold was verified by testing the new assembly in static compression.

Figure 1. View of the setup for the Cobra telescopic sighting unit 35-degree sled test.

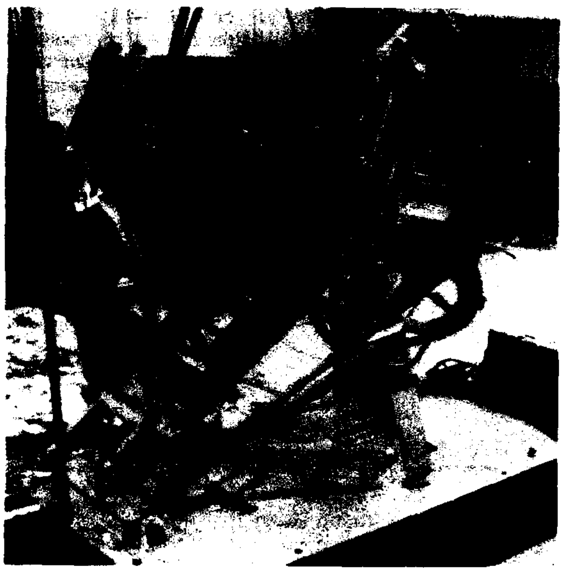

Figure 2. View of the setup for the Apache optical relay tube 35-degree sled test.

4.2 Restraint System

One of our objectives in conducting this study was to examine the ability of the restraint system, including the MA-8 rate sensitive inertia reel, to prevent head strikes on the sighting system during crashes when the inertia reel was placed in the automatic mode. We did this in two ways. First, we ran tests at two lock activation settings: 1.2-1.8 g (nominally, a 1.5 g setting), and 1.5-3.5 g (nominally, a 2.25 g setting). These levels refer to the linear acceleration of the strap as it unwinds from the inertia reel.

As an alternative approach to changing the locking parameters, we used the MA-10, a new type of inertia reel which has a dual acceleration sensing system. One part of this system operates much like the standard (i.e, MIL-4-8236) MA-6 and MA-8 reels. This was set to lock at 1.2-1.8 g linear acceleration of the unwinding strap. The second part of the MA-10, which senses the impact accelerations of the seat pan, was set to activate the lock at 4-5 g in the x- or z-axis.

4.3 Test Manikin

The test subject was a 50th percentile Hybrid III automotive manikin with a nominal weight of 80 kg and a stature of 178 cm. This manikin was designed in the early 1970s to improve the biofidelity of impact response of the U.S. Department of Transportation standard (Part 572) anthropomorphic test device, referred to as Part 572 ATD. The manikin was dressed in an Army flight suit and boots, and its head fitted with either the SPH-4 aviator helmet for the Cobra tests or the integrated helmet and display sighting system (IHADSS) helmet for the Apache tests. Although the manikin had a usual Hybrid III neck, the head itself was modified from a Part 572 head to allow the use of a frangible face, an element designed and fabricated at NBDL.

The frangible face consisted of a core of foam and aluminum mesh covered by a 15-mil (0.381 mm) thick aluminum witness plate, all covered by a silicon rubber humanoid skin. This face was mounted on the manikin head which had its face removed and a flat mounting plate welded in its place. When the face impacted a structure during a test, the underlying foam and aluminum structures deformed permanently. Post-test examination of the face indicated whether or not the face (i.e., head) struck the ORT or TSU. Additional indication of any head contact with the viewing structure was obtained by rubbing blue chalk over potential strike locations of the ORT and TSU. Upon the completion of a test, any blue chalk marks found on the face indicated a head strike.

4.4 Airbag Hardware

In the second phase of this project, the standard restraint system was supplemented with an air cushion system mounted at a convenient location on the ORT or TSU. Our goal in this phase was to explore the concept of using air cushions to improve the effectiveness of the current restraint system in reducing the severity of head strikes on the sighting system during crash tests.

We selected an off-the-shelf and locally available automotive airbag system. The system was a driver's side airbag for the Honda Motor Company supplemental restraint system of its Acura Legend model. Since our objective was to demonstrate the concept and not to develop a customized version of the air cushion, we only added minimal modifications to the external mounting hardware to allow the airbag to function as intended. For example, the automotive airbag used in the tests was designed to take advantage of the steering wheel rim to provide a back support during its inflation and potential driver's head and chest movements into it. Because neither the TSU nor ORT had such a rim, it was necessary for us to fabricate and install a reaction plate that provided the back support needed for proper functioning of the airbag. Eventually, airbags would have to be custom-tailored to the specific cockpit environment without unduly interfering with the copilot controls.

4.5 Documentation

Two onboard high-speed film cameras, each running at 500 frames/second, were used to record the motion of the manikin head, the restraint system, head strikes, and airbag deployment. One camera was mounted on the left side of the sled while the second was mounted above and behind the seat in order to view the manikin head and shoulder and the unwinding of the shoulder strap out of the inertia reel. In the second phase of testing, these cameras were supplemented by a 200 frames/second video camera for quick look, and two 1000 frames/second film cameras, all placed offboard.

Head-mounted accelerometers were used in both phases of testing to record linear triaxial accelerations of the head. In the second phase, two angular accelerometers were added to record head roll about its forward axis and pitch about its lateral axis. In all tests, sled acceleration was recorded. Whenever possible, the unwinding of the shoulder strap out of the inertia reel was monitored using a string potentiometer. The potentiometer was installed near the inertia reel housing and its string end attached to a convenient point on the moving strap.

4.6 Analysis methods

Two primary categories of data were generated during the testing: transducer signals and high-speed films. Less formal but equally informative were the observations recorded on the spot during each test by the investigators and still photographs which were taken at various stages of each test. High-speed films provided visual records of the impacts and were reviewed to identify hardware failures and to understand the interaction between the manikin and the restraint system.

Transducer data were the primary basis for assessing the severity of head strikes with the sighting systems and, hence, the success or failure of the restraint system. Each signal was digitized at the rate of 8000 samples per second, and filtered using low-pass 4-pole Butterworth digital filters at one of the following corner frequencies: 1650 Hz for head linear accelerations, 100 Hz for sled pulses and head angular accelerations, and 300 Hz for shoulder belt extension signals.

Further signal processing included integration of sled acceleration pulse to produce a velocity time-history, from which the velocity change could be extracted. Head accelerations included the forward, lateral, and longitudinal components, as well as their resultant, defined as the point-by-point square root of the sum of the squared components. The head injury criterion (HIC) also was derived from the resultant head acceleration. Angular accelerations of the head (pitch and roll) were integrated to produce angular velocities.

Belt extension, obtained with a potentiometer, was differentiated with respect to time to produce the rate (m/s) at which the belt was unwinding from the inertia reel. In the absence of direct transducer measurement, a second differentiation was done to produce the acceleration (g) at which the belt was moving. Belt acceleration triggers the locking mechanism in both the MA-6/8 and the MA-10. Linear acceleration obtained by differentiation is noisy and must be heavily smoothed before a recognizable signal is produced.

5. RESULTS AND EVALUATION

In general, vertical impacts were simulated on horizontal sleds by aligning the seat back with the horizontal sled tracks. Because of gravity, the downward weight of the manikin combined with the acceleration forces to produce a thrust vector which slightly inclined relative to the sled horizonal axis. Therefore, to generate impact forces along the manikin spinal (longitudinal) axis, the seat was rotated by an offset angle determined by the average sled acceleration. A seat back angle of 5 degrees with the horizontal was considered adequate compensation for the effect of gravity in our tests. Three directions, defined by seat back angles of 5, 20, and 35 degrees with respect to the tracks, were designed to generate impact forces directed 0, 15, and 30 degrees, respectively, from the spinal axis.

5.1 Description of Tests

Two crash severities were simulated. The two acceleration pulses selected differed primarily in the magnitudes of the acceleration (25 and 7 g nominal peaks) while essentially maintaining the same velocity of 11-12 m/s. The 25-g pulse simulated a severe but survivable crash. The 7-g pulse was intended to simulate the first 70-80 ms portion of a collapsing load-limiting landing gear where the acceleration dwells at the 7-g level. In a typical crash involving the landing gear, the long-duration, low-level pulse may be followed by a 50-100 g peak pulse which is generated as the landing gear bottoms out. Since this complex acceleration pulse was not achievable with the NBDL sled, we deemed it was more important to simulate the early portion of the impact with the available sled. Tests that did not involve the airbag are listed in Table 1 for the Cobra and in Table 2 for the Apache. Tests with repeated or similar test conditions have been grouped together even though they may have been conducted in a different order, as reflected by their test reference numbers.

Table 1. Summary of conditions and results of the inertia reel tests with the Cobra telescopic sighting unit.

Test reference number	Sled pulse		Pitch angle (deg)	Head resultant acceleration		Angular acceleration swing at impact		Angular velocity swing at impact	
	Acceleration (G)	Velocity (m/s)		Peak (G)	Head injury criterion	Roll (rad/s^2)	Pitch (rad/s^2)	Roll (rad/s)	Pitch (rad/s)
LX6196	19.6	11.1	5	42.4	157	305	3 010	2.1	30.5
LX6197	19.0	11.0	5	43.3	119	455	3 680	3.0	35.2
LX6198	19.6	11.0	5	40.3	102	505	3 935	3.1	32.8
LX6199	23.5	12.0	5	60.6	249	995	5 600	4.0	40.8
LX6200	23.4	12.0	5	65.7	250	805	5 250	3.6	43.2
LX6201	23.4	12.0	5	49.8	245	700	5 505	5.1	40.0
LX6203	25.0	12.3	35	138.3	**	3 000	17 000	13.9	79.5
LX6204	25.0	12.3	35	128.8	1 244	2 720	11 500	8.6	61.0
LX6274	25.0	11.1	35	86.9	498	1 295	10 320	4.5	73.6
LX6275	25.0	11.1	35	141.8	594	4 160	18 560	8.4	86.5
LX6276	25.1	11.2	35	195.0	615	1 425	8 700	6.2	54.4

** Data unavailable.

Table 2. Summary of conditions and results of the inertia reel tests with the Apache optical relay tube.

Test reference number	Sled pulse		Pitch angle (deg)	Head resultant acceleration		Angular acceleration swing at impact		Angular velocity swing at impact	
	Acceleration (G)	Velocity (m/s)		Peak (G)	Head injury criterion	Roll (rad/s²)	Pitch (rad/s²)	Roll (rad/s)	Pitch (rad/s)
LX6208	7.7	10.7	35	93.5	159	1 550	14 000	4.8	50.4
LX6209	6.7	10.7	35	31.8	42	535	6 040	3.0	48.0
LX6210	6.8	10.7	35	27.4	35	580	5 840	2.6	41.6
LX6211	6.8	10.7	35	39.9	51	695	7 420	2.5	48.0
LX6212	6.8	10.8	35	26.2	27	505	7 020	1.3	3[illegible]5
LX6213	6.8	10.7	35	35.4	55	695	7 440	2.9	51.2
LX6277	8.9	10.8	35	52.6	82	1 040	6 800	2.3	40.8
LX6283	25.9	11.4	35	251.4	1 357	3 970	124 000	15.2	54.4
LX6214	6.8	10.8	20	80.5	126	855	16 000	2.5	46.5
LX6215	6.8	10.7	20	53.0	68	800	8 880	2.6	49.6
LX6216	6.8	10.7	5	70.5	99	11 070	11 600	3.0	47.2
LX6217	6.7	10.8	5	15.8	**	**	**	**	**

** Data unavailable or clearly inaccurate.

Table 3. Summary of conditions and results of G-triggered airbag sled tests simulating 35-degree impact.

Test reference number	Sled pulse		Tested system	Head resultant acceleration		Angular acceleration swing at impact		Angular velocity swing at impact	
	Acceleration (G)	Velocity (m/s)		Peak (G)	Head injury criterion	Roll (rad/s²)	Pitch (rad/s²)	Roll (rad/s)	Pitch (rad/s)
LX6270	20.3	10.8	Cobra TSU	43.2*	207*	830	2 815	4.9	29.4
LX6271	23.2	11.5	Cobra TSU	43.6*	190*	575	3 840	6.5	23.2
LX6272	25.0	11.2	Cobra TSU	42.7*	133*	1 840	3 020	11.2	15.6
LX6273	24.7	11.1	Cobra TSU	52.9*	168*	1 470	**	6.8	**
LX6278	6.7	9.0	Apache ORT	13.0	26	465	1 500	2.9	8.0
LX6279	7.1	9.3	Apache ORT	14.6	35	470	1 100	1.7	4.6
LX6280	27.8	11.7	Apache ORT	210.4	1 566	2 350	11 440	15.4	40.8
LX6281	25.5	11.3	Apache ORT	67.7	398	1 280	3 650	13.4	20.3
LX6282	25.6	11.7	Apache ORT	95.7	569	1 840	6 600	14.6	34.8

* *Actual peak slightly higher than indicated.*
** Data unavailable or clearly inaccurate.

5.2 Results of Tests

Detailed results of the tests may be found in a recent U.S. Army Aeromedical Research Laboratory (USAARL) technical report [9]. Selected response parameters are summarized in Tables 1, 2, and 3. These include peak resultant linear acceleration (g) of the head and the computed HIC. The head angular motion is reported in the tables as the "swing" between the low and high nearest the time of head strike. Swings of angular accelerations (rad/s²) and velocities (rad/s) are tabulated for both roll and pitch. Head pitch is defined as a rotation of the head about its lateral (Y) axis. Head roll is defined as a rotation of the head about its forward (X) axis.

Valid measurements of the amount of extension of the restraint belt out of the inertia reel are listed in Tables 4, 5, and 6. When signal processing results did not agree, within reasonable tolerance, with observations from high speed films, the measurements were discarded as erroneous. In many tests, it was possible to estimate the belt extension from film analysis by relying on the checkered pattern attached to the belt. In fact, this was the only method available for measuring the belt extension when the signal from the string potentiometer was clearly in error (because of a breakdown in the instrumentation).

Table 4. Restraint system and manikin interaction with the TSU in the Cobra tests.

Test number	Inertia reel		Belt extension (cm)	Head/helmet strikes (film analysis)
	Type	Lock setting (G)		
LX6196	MA-6/8	2-3	1.5*	None.
LX6197	MA-6/8	1-2	3.0	None.
LX6198	MA-10	1-2/4-5	6.5	None.
LX6199	MA-10	1-2/4-5	2.0*	Helmet (minor).
LX6200	MA-6/8	1-2	8.0	Helmet (minor).
LX6201	MA-6/8	2-3	10.8	Face (minor)
LX6202	**	**	**	Chin, cheek.
LX6203	MA-10	1-2/4-5	17.5	Right cheek.
LX6204	MA-6/8	1-2	**	Full face.
LX6274	MA-6/8	Prelocked	3.5	Full face.
LX6275	MA-6/8	Prelocked	2.0	Right cheek.
LX6276	MA-10	Prelocked	11.0	Full face.

* Estimated from film analysis.
** Data unavailable or clearly inaccurate.

Table 5. Restraint system and manikin interaction with the ORT in the Apache tests.

Test number	Inertia reel		Belt extension (cm)	Head/helmet strikes (film analysis)
	Type	Lock setting (G)		
LX6208	MA-10	1-2/4-5	5.4*	Full face.
LX6209	MA-6/8	2-3	5.7*	Full face.
LX6210	MA-6/8	1-2	7.0*	Full face.
LX6211	MA-10	1-2/4-5	5.7*	Right face.
LX6212	MA-6/8	2-3	12.0	Lower face
LX6213	MA-6/8	1-2	5.7*	Full face.
LX6277	MA-10	prelocked	4.9*	Full face
LX6283	MA-10	1-2/4-5	21.8	Head impact.
LX6214	MA-10	1-2/4-5	4.5	Left face.
LX6215	MA-6/8	2-3	4.5	Forehead.
LX6216	MA-6/8	1-2	3.2*	Forehead.
LX6217	MA-10	1-2/4-5	**	Forehead.

* Estimated from film analysis.
** Data unavailable or clearly inaccurate.

Table 6. Restraint system and manikin interaction with the airbag and with the ORT or TSU.

Test number	Inertia reel		Belt extension (cm)	Observations from film analysis
	Type	Serial number		
LX6270	MA-6/8	**	5.9	No head/TSU contact
LX6271	MA-10	134	4.6	No head/TSU contact
LX6272	MA-10	135	**	No head/TSU contact
LX6273	MA-10	137	**	No head/TSU contact
LX6278	MA-10	139	6.0	Head/chest (airbag)
LX6279	MA-10	140	5.4	Head/chest (airbag)
LX6280	MA-10	141	15.8	Head strike (ORT)
LX6281	MA-10	141	10.8	Head impact (airbag)
LX6282	MA-10	142	12.9	Head impact (airbag)

** Data unavailable or clearly inaccurate.

Also reported in Tables 4 through 6 are qualitative evaluations of the high-speed films of the tests and examinations of posttest photographs. All test films were reviewed to detect and report unusual events which could help explain certain signals or the final outcome of some tests. Film reviews focused on two areas of concern: the extension of the restraint belt out of the inertia reel, and the head strikes with the TSU or ORT.

Head strikes with the TSU or ORT also were easily detected from the head acceleration signals and by posttest examination of the frangible face. Figure 3 is a typical exhibit of mild deformations produced by the tests. Figure 4 shows a typical example of severe deformations by the tests. Evidence of head strikes in some ORT tests also was obtained from the shearing of the nylon screws and the collapse of the ORT into its base, as shown in Figure 5.

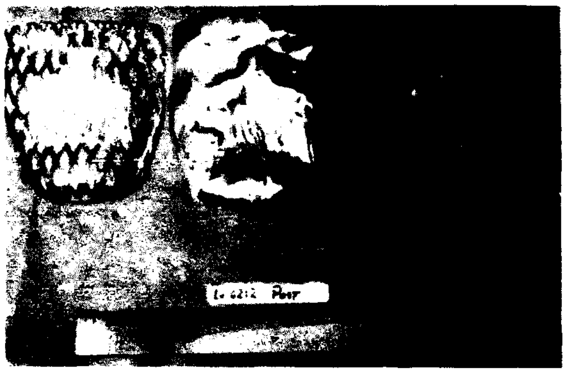

Figure 3. Exhibit of typical mild deformation of the manikin frangible face produced by a head strike against the sighting unit.

Figure 4. Exhibit of typical severe damage to the manikin frangible face produced by a head strike against the sighting unit.

6. DISCUSSION

The epidemiological data we examined and the tests we performed in this study indicate the TSU and the ORT pose a substantial hazard to copilot/gunners in the event of a crash. The most common serious injury is facial injury, frequently associated with severe brain trauma and death. The preliminary nature of this study limited the number and type of tests that were conducted. It also restricted the exploration of the airbag concept to the use of off-the-shelf hardware with minimal allowance for hardware redesign or modification. Despite these limitations, we have demonstrated a problem exists and shown a supplemental airbag is a viable solution.

In this study, we calculated the HIC from manikin head linear acceleration to provide an additional tool for evaluating the severity of head strikes. We should caution that the validity of HIC as a predictor of head injury depends on several conditions which must be strictly met. For example, the validity of HIC prediction becomes questionable if there were no head strikes with the ORT or TSU. Even in case of a head contact, the HIC generally is considered invalid if the duration of contact exceeds 15 ms. Usually, the duration of contact is much longer than the interval over which the HIC is determined. Finally, the HIC should not be used as a pass-fail criterion; instead, it should be used to assign probability of irreversible brain injury occurring. Thus, assuming all conditions for using the HIC have been satisfied, HIC values of 500, 1000, and 1500 may be converted respectively to 5, 15, and 50 percent approximate probabilities of brain injury [10].

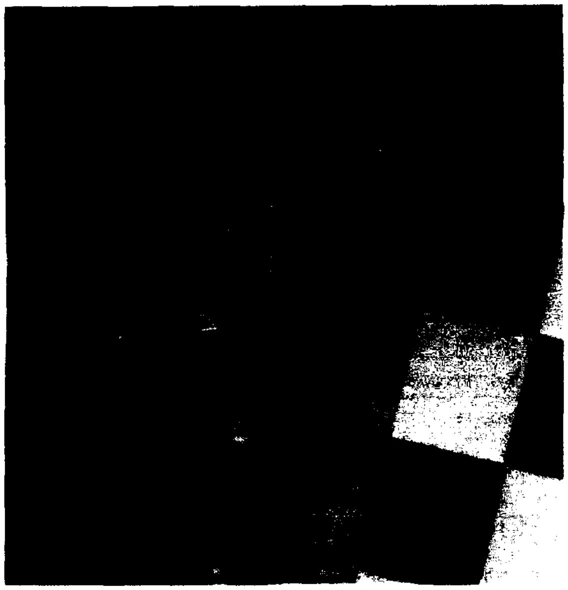

Figure 5. Photograph of the observed damage to the Apache optical relay tube produced by a head strike.

Furthermore, we must emphasize that HIC is a predictor of *closed brain injury* resulting from impacts to the calvarium. Most fatal TSU injuries were open brain injuries arising from impacts to the face. The significance of this finding is that facial bones are considerably weaker than the more dense calvarial bones and yield under relatively low force. In a facial impact with the TSU/ORT, brain injury occurs as a direct intrusion of collapsing facial bones and not from the brain's inertial response to an applied force. Under these restrictions, the HIC probably is not an accurate predictor of serious injury. In this study, we use it as a relative indicator for comparing the severity of different head strikes.

6.1 Discussion of Inertia Reel Tests

Results of the TSU tests (Tables 1 and 4) show for the six nearly vertical (5-degree) simulated crashes, head strikes were associated with lower head accelerations and HIC values than those produced by the five more pitched (35-degree) tests. That is, the severity of head strikes was lower for vertical impacts than for those with large horizontal components.

We may attribute differences in the severity of head strikes to the trajectories relative to the impact vector produced in the two groups. At the onset of a nearly vertical impact, the head and body of the pilot travel along a vertical path that does not pass through the sighting unit. As the pitch angle of impact increases, a greater horizontal component is added to the impact vector, so the initial path of travel of the pilot's body and head passes near or through the sighting system. The head trajectory is complicated further by the unavoidable slack of the shoulder belt which is produced automatically by the slumping of the upper torso. As a result, the pilot's head would likely strike the sighting system, even when the impact primarily is vertical. This explanation is supported by field data which show TSU impact is strongly dependent on longitudinal velocity at impact and only weakly dependent on vertical velocity.

In general, our tests were inconclusive regarding the relative effectiveness of the different inertia reels and lock settings. Using amount of belt extension and head pitch angular accelerations as indicators of inertia reel performance, the results were quite inconsistent. In the six nearly vertical TSU tests, belt extensions varied between 1.5 and 10.8 cm. Although all reels locked, three runs had belt extensions that exceeded 6 cm, one run for each inertia reel condition. Ideally, belt extension should be limited to the extent possible and, preferably, to less than 5 cm in order to prevent flail injury. We were unable to explain the wide variation in belt extensions for essentially identical test conditions.

We observed the same degree of variability of belt extension in severe TSU runs even when we prelocked the reels. Test LX6203 used a MA-10 dual sensing reel and the belt extension obtained from a string potentiometer signal was 17.5 cm. We were unable to confirm this value from test film or onsite observations. The same uncertainty of belt extension applies to test LX6204, so we cannot directly ascertain whether or not the two inertia reels locked upon impact. However, peak linear head accelerations (138.3 and 128.8 g), head pitch acceleration swings (17,000 and 11,500 rad/s^2), and pitch velocity swings (79.5 and 61.0 rad/s), as well as the damage to the frangible face, are strong indicators that the two inertia reels did not properly lock allowing the head to strike with such severity that it would have caused serious head injuries in a real crash.

Three Cobra TSU tests, LX6274, LX6275 and LX6276, were conducted later in the study under test conditions similar to the two severe TSU tests discussed above. This time, extensions of the belt were monitored with a string potentiometer, a reasonable, reliable, and accurate transducer. These were run with a prelocked inertia reel in order to verify our hypothesis that head strikes do occur, even if the restraint system were given the best chance of functioning properly. Two of the tests resulted in belt extensions of 3.5 and 2.0 cm, indicating the belt remained tight and did not extend. Immediate posttest examination of the inertia reel confirmed this assertion. The third test produced an extension of 11 cm, indicating some slippage of the reel or a stretch of the belt must have occurred. Posttest observations indicated the reel, in fact, did lock.

Regardless of the action of the inertia reels or restraint belt, head strikes did occur in tests, as indicated by observed damage to the frangible faces and head acceleration signals. Peak head accelerations in the 85 to 195 g range and HIC values near 600 produced by all the 35-degree pitch tests were sufficient to cause facial fractures and lacerations and, possibly, irreversible brain damage in actual mishaps.

The Apache ORT tests (Tables 2 and 5) were all run at 7 g sled pulse to simulate the early portion of collapse of the landing gear during a crash. All these tests produced head strikes to the ORT regardless of inertia reel configuration. No inertia reel configuration produced consistently better results, as in the TSU test series. Belt extensions remained below 7 cm, except for test LX6212 where the restraint belt extended by 12 cm. Even then, the HIC and peak acceleration of this test were the lowest among this group, despite obvious damage to the frangible face. The highest head linear acceleration for this series was 94 g in test LX6208 and the highest HIC value was 160 for the same test, an indication of the relative "mildness" of head strikes.

Nevertheless, all accelerations exceeded facial bone tolerances to fracture. Also, it should be remembered that these tests only simulated crashes where the landing gear did not fully stroke. In crashes that exceed the landing gear sink speed, the 7 g pulse will be followed by a considerably higher magnitude pulse, potentially leading to a secondary ORT strike more severe than the initial strike.

6.2 Discussion of Airbag Tests

After preliminary review of data from the first phase, we decided to focus the second phase of testing on simulations of "severe" crashes. After all, if the airbag were to be introduced into the Cobra and Apache to supplement the current restraint systems, it would be primarily to prevent injury in the severest of head strikes. All tests with airbags were designed to simulate the 35-degree impact as described in Table 3. Although LX6269 was a full-scale airbag test, no manikin transducer signals could be processed. Results from 10 (4 Cobra and 6 Apache) airbag tests are in Tables 3 and 6.

In all airbag tests, the manikin's head rebounded after being stopped by the airbag and struck the armored seat. This rebound action is undesirable and would have been eliminated or reduced with refinement of the airbag deployment or the design of an airbag specifically for Cobra or Apache. The rebound impact produced lower acceleration levels than earlier interaction with the airbag or the underlying support structures. Generally, head contact with the airbag lasted more than 15 ms, so the HIC as an injury assessment tool was not valid. However, the HIC was used only for the purpose of comparing one test to another and not to predict injury.

The four Cobra TSU airbag tests (LX6270 through LX6273) produced consistent results. As noted in Table 3, true peak head accelerations may be slightly higher than those given for the four TSU tests. The MA-6 in test LX6270 and MA-10 in LX6271 appear to have locked and restricted the belt extensions to under 5.9 cm. Angular pitch accelerations recorded in test LX6273 suggest the inertia reel may have failed to lock.

The remaining six airbag tests were Apache ORT tests. Two of these tests were run at the lower crash pulse severity (7 g, 9 m/s) to simulate the early portion of landing gear collapse during a crash. These were test conditions similar to the seven nonairbag tests (LX6208 through LX6213, and LX6277) reported in the top half of Table 2. This similarity of the two groups allows direct comparisons between the head strike parameters to determine the effects of supplementing the restraint system with an airbag. The last four tests reported in Table 3 have no direct counterpart in Table 2. All MA-10 inertia reels locked during the ORT tests; however, belt extension appeared to be excessive for all 25 g runs. This is particularly true for LX6280 where the belt extension was 15.8 cm and head pitch acceleration was 11,440 rad/s^2.

In order to evaluate the effect of the airbag on head strikes, we compared the four Cobra airbag tests to the group of five nonairbag tests discussed earlier and presented in the bottom half of Table 1. The two groups simulated the same 35-degree impact angle, and the severity of the crash pulses essentially were the same. In all runs except LX6273, the inertia reels appeared to lock properly. Aside from minor variations in the test conditions, the primary difference between the two groups was the presence of the airbag. Therefore, any improvement in the response parameters may be reasonably attributed to use of the airbag. We made a similar comparison between the two Apache airbag tests and the seven nonairbag tests.

The small number of tests did not allow formal statistical analysis of the reduction of severity. However, the trend is so clear that some characterization of the improvement is possible. To this end, we compared the average values of four parameters: Peak head accelerations (g), the HIC, and the swings of head pitch accelerations (rad/s^2) and velocities (rad/s) at the instant of head strike. In using these parameters, no injury prediction was made. Rather, the parameters were used as indicators to assess the mitigating effects of the airbag on the severity of simulated head strikes. The average value is defined simply as the sum of observed values divided by the number of observations. No other statistics were derived because of the small number of observations. Results of comparisons, summarized in Table 7, clearly demonstrate the effectiveness of the airbag in reducing the severity of head strikes with the TSU in the Cobra and with the ORT in the Apache.

Table 7. Effect of airbags on the means of four head response parameters.

Test group and improvement due to airbag	Linear Accel. (A)	HIC (B)	Angular accel. (C)	Angular veloc. (D)
Cobra TSU tests:				
(1) Without airbag	114.0	871	12 850	70.5
(2) With airbag	47.8	170	3 328	22.5
% Improvement	*66*	*80*	*74*	*68*
Apache ORT tests:				
(3) Without airbag	59.9	93	9 920	40.5
(4) With airbag	13.8	31	1 300	6.3
% Improvement	*77*	*67*	*87*	*84*

Parameters:
(A) Head peak resultant linear acceleration (g).
(B) Head Injury Criterion.
(C) Head pitch angular acceleration (rad/s^2) swing at impact.
(D) Head pitch angular velocity (rad/s) swing at impact.

Test groups:
(1) Five tests: LX6203, LX6204, LX6274, ... LX6276.
(2) Four tests: LX6270, ... LX6273.
(3) Seven tests: LX6208, ... LX6213, LX6277.
(4) Two tests: LX6278, LX6279.

7. CONCLUSIONS

In this study, we presented epidemiologic, experimental, and analytical evidence to support the following conclusions:

- The probability of striking the sighting system mainly depends on the crash dynamics and, particularly, on the longitudinal velocity at terrain impact. Aircraft roll or yaw at impact may be influential in directing the head trajectory away from the sighting system, and may account for the relatively small percentage of ground impacts resulting in head strikes.

- During a mishap involving the Cobra or Apache attack helicopters, the copilot/gunner is at risk of striking his head against the TSU in the Cobra or the ORT in the Apache. This occurs in spite of the correct use and proper functioning of the standard restraint system.

- Our tests did not produce a clear pattern showing an advantage in using dual-mode inertia reels to provide the solution to excessive upper torso strap extension identified from crash investigations and other sled tests. An inertia reel that gives more consistent results should be developed and qualified to anticipate dynamic conditions.

- For optimum protection of the copilot/gunner in attack helicopters, our preliminary study demonstrated a clear reduction in head strike severity when an airbag is utilized to supplement current restraint systems. We support further studies to customize the design of the airbag and to optimize its operational parameters. We believe the airbag concept is a vital element in the overall U.S. Army effort to delethalize all helicopter cockpits.

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PRE-FLIGHT RISK ASSESSMENT IN EMERGENCY MEDICAL SERVICE (EMS) HELICOPTERS

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1. SUMMARY

The Emergency Medical Service (EMS) industry has been the subject of several television and newspaper articles (Harvey and Jensen, 1987) which emphasized the negative aspects, (e.g., fatalities and high accident rates), rather than the life saving services performed. Until recently, the accident rate of the EMS industry has been five times as high as that of other civil helicopters. This high accident rate has been coupled with the dramatic rise in the number of programs. The industry has built from a single service at its inception in 1972, to over 180 in 1987 (Spray, 1987), to the point that 93% of the contiguous U. S. is now covered by some type of EMS service. These factors prompted the National Transportation Safety Board (NTSB) to study the accidents that occurred between May 11, 1978 and December 3, 1986 (NTSB, 1988). The NTSB report concluded that "Sound pilot judgment is central to safe flight operations." They further stated that "... factors unique to EMS helicopter operations--such as the influence of the mission itself, program competition, and EMS program management perspectives--*can drastically influence pilot judgment during the EMS mission.*" One of the most difficult decisions that a pilot must make is whether to accept or decline a mission. A pre-flight risk assessment system (SAFE) was developed at NASA-Ames Research Center for civil EMS operations to aid pilots in making this decision objectively. The ability of the SAFE system to predict mission risk profiles was tested at an EMS facility. The results of this field study demonstrated that the usefulness of SAFE was highly dependent on the type of mission flown. SAFE is now being modified so that it can "learn" with each mission flown. For example, after flying a mission to a particular site, an EMS pilot would input information about this mission into the system, such as new buildings, wires, or approach procedures. Then, the next time a pilot flew a similar mission or one to the same area, this additional information would be taken into account in computing a risk assessment.

2. INTRODUCTION

The emergency medical service (EMS) industry in the United States has received a great deal of negative publicity. In the late 1980s, it was the subject of a CBS news documentary (February, 1987) as well as numerous newspaper articles (Harvey and Jensen, 1987; Harvey, 1986) and television reports. These reports focused on a series of fatal accidents and highlighted the fact that the accident rate for EMS helicopters was about five times that of other civil helicopters. This negative publicity created a public impression of an unsafe industry. While it is true that the accident rate was on the rise, it is also true that the number of EMS programs has increased, from a single service at its inception in 1972 to the point where now 93 % of the contiguous United States is served by some form of helicopter air ambulance service. The issue of EMS safety prompted the National Transportation Safety Board (NTSB) to conduct a study (NTSB, 1988) investigating the EMS accidents between May 11, 1978 and December 3, 1986. The NTSB investigated 59 accidents involving EMS helicopter operations. One clear conclusion of this study was that: "...poor weather conditions pose the greatest single hazard to EMS helicopter operations." While the operators are regulated by Federal Air Regulations (14 CFR Part 91 and Part 135) both of which set weather minimums, portions of the rules are subject to pilot interpretation. For example, the pilot has considerable latitude in deciding whether to proceed with a mission in limited visibility. A recent study (DOT, 1991) found that night cross-country weather minimums were exceeded 9.3 % of the time. Thus, based upon the number of limited-visibility accidents, the NTSB recommended more stringent daytime visibility minimums. Based upon these regulations, the pilot's knowledge of the area, and weather patterns, the pilot must make the decision to accept or decline a mission.

A recent survey has been conducted of EMS accidents since 1986 and a review of EMS accidents submitted to the Aviation Safety Reporting System (Dodd, 1991). It found that, while the accident statistics had improved dramatically in recent years, the same factors cited as causal or contributory in the early study still exist in current operations. This suggests that the recent decline in fatalities may be somewhat more fortuitous than the result of a fundamental change in the system.

The EMS pilot is in a unique situation in aviation. Often, poor weather conditions lead to accidents for which an EMS unit is called. However, the same adverse weather precipitating the accidents also result in mission risk. Further, the decision to accept or reject flights is literally a life or death choice. The medical team and hospital administration may exert pressure, possibly inadvertently, on the pilot to accept a flight in marginal weather in order to try and save a life. In addition, the EMS pilot has no aviation peer group immediately available with whom he can analyze the situation. In contrast, most other pilots are accustomed to discussing such situations with other pilots or flight operations people in airports or pilot ready rooms. The EMS pilot's decision is subject to many influences in addition to the weather; the type of mission, competition with other EMS operators, crew, organizational, environmental and aircraft factors all exert an influence on the pilot's decision. The influence of these factors and their interaction provide a difficult framework within which to make a decision. For example, the management of the company contracted to provide EMS operations to a hospital may be located thousands of miles away. This, coupled with a helicopter pilot's "can do" attitude and the challenge of a life saving mission, can affect sound pilot judgment (Albert, 1987). The above example illustrates that the interaction of organizational, crew, and mission factors may lead to risky decision making. Further complications can result from program competition. The NTSB report found that it is a common practice for the ground personnel to call a second EMS operator after being refused service by another EMS operator or public service organization due to weather or other high risk conditions.

Due to the complicated interaction among the above factors, the pilot's decision to accept or reject a mission is an area that would benefit greatly from a decision aid that could evaluate the situation on an objective basis, free from outside influences. The U.S. Army and the Coast Guard have tested such systems to assess mission risk. The present system, Safety Assessment for Flight Evacuation (SAFE), builds upon this earlier work, but was designed specifically for civil EMS operations.

2.1 Previous Risk Assessment Systems

The U.S. Army developed a system for pre-flight mission risk assessment. This is the Aviation Litmus Evaluation Risk Test (ALERT) described by Boley (1985). ALERT is a paper and pencil test based upon six factors: 1) supervision, 2) planning, 3) crew selection, 4) crew endurance, 5) weather, and 6) complexity.

A nine-cell matrix was developed for each of these factors, and "risk values" from 1 (lowest risk) to 5 (highest risk) fill the cells of the matrix. For example, the matrix for weather condition is shown in Table 1. Three levels of winds are crossed with three levels of visibility to create the nine cells of the weather matrix.

Table 1. Risk Value Matrix - Weather (ALERT)

		Visibility		
		Clear	VFR	Minimums
W	30	3	4	5
I	20	2	3	4
N	10	1	2	3
D				

The values for each of the six factors are then added to calculate the ALERT value. The ALERT value for this specific mission is compared to a 30 point scale subdivided into three major categories: (1) Low risk (0-12), (2) Caution (13-23), and (3) High risk (24-30). Thus, the system provides the pilots with an objective risk assessment to aid in the decision process.

The Army system was modified for use by the U.S. Coast Guard in Medivac operations (McLean, 1986). It was described in the October 1987 issue of AIRNET (Fedorowicz, 1987). Risk Evaluation and Aviation Resource Management (REARM) maintained the basic structure of ALERT, but modified and extended some of its attributes, such as the verbal descriptions in the matrices. For example, the three mission types were changed from: (1) support, (2) nap of the earth, and (3) night vision goggles, to: (1) site, (2) hospital, and (3) scene. In addition, two of the matrices (crew experience and weather) were increased to twelve cells. Table 2 displays the weather matrix for REARM.

Table 2. Risk Value matrix - Weather (REARM)

		Visibility		
		Clear	VFR	Minimums
W	30	3	4	5
I	>20	2	3	4
N	>10	1	2	3
D	<10	3	4	5

The weather matrix was further modified to account for winds in excess of 30 knots (adding one to the score for each 10 knots over 30) and night missions (multiplying the score by 2.5). The REARM scale ranges from 6 to 40 and is divided into four areas: (1) Normal (6-16), (2) Caution (17-25), (3) Coordination Required (26-35), and (4) Danger (36-40). This value predicts the risk of the mission and recommends the appropriate level of supervision required to make the final decision.

2.2 Development of SAFE

SAFE (Shively, 1988) builds upon this earlier work to create a system specifically designed for civil EMS operators. SAFE is programmed on a personal computer for speed and efficiency. A PC-based expert building tool, EXSYS, was employed to develop this system. SAFE allows the interaction of many factors to be considered through the complex relationships of the if-then conditional statements in its database. SAFE further allows the most important factors to be given more weight in the final score. For example, weather has been cited as the single most important cause of EMS accidents, therefore it is given a greater weight than is level of supervision. In the earlier systems, all the factors were given equal weight. Automating this type of system has several advantages; (1) Data can be entered and risk assessments generated more quickly, (2) it is faster and allows greater complexity and flexibility. A greater number of individual factors can be considered, as well as the important interactions among those factors. In the two previous systems, each matrix was isolated functionally and computationally from each other matrix. Clearly, the interaction of factors such as level of supervision, crew experience, and weather, can interact to affect sound judgment, and these should be considered jointly. However, this is computationally difficult with a paper and pencil system.

A further advantage of a computerized system is automatic data collection. The report generator option allows data files to be saved that contain the time, date, mission data, and subsequent SAFE scores. This database allows SAFE to be updated and improved as more is learned about the factors that lead to risky decision making. This record can also be used as a log of activities as well as a source of training materials. For example, a new EMS pilot could study the patterns of factors that has led to good or poor decision making.

2.3 Knowledge-base Development

To develop the system, initial discussions were held with EMS pilots, flight nurses, and program administrators. Their suggestions, along with the information from the NTSB report, other published data, and the earlier systems, served as the basis for developing a questionnaire. This questionnaire contained five types of factors: (1) Mission, (2) Crew, (3) Organizational, (4)Environmental, and (5) Aircraft. Each of these factors was subdivided into as many as eight variables that could affect the risk of a mission. Subject matter experts were asked to rank order the influence of each of the variables. As an example, the variables for crew factors are shown in Table 3 below. These are presented in the order of importance as assigned by one of the subject matter experts.

Table 3. Crew Factors

1- EMS experience of pilot
2- IFR currency of pilot
3- Crew rest
4- Pilot's familiarity with area
 a- en route
 b- at site
5- Pilot's familiarity with aircraft
6- Number of pilots/aircraft
7- Hours since last meal
8- Commercial rating

Thus, for the crew factors, EMS pilots and other EMS personnel rated EMS experience to be the most important of the crew factors, and a commercial rating to be the least important. The data and suggestions from this study provided the database for the development of a prototype version of SAFE.

2.4 Operational Testing

SAFE values were computed for every mission flown during a three-week period at an EMS operator; thirty-seven missions covering both night and day operations were included in the study. This operator employed four pilots flying a BK-117 helicopter. All of the missions were flown single-pilot VFR with a medical crew generally consisting of a flight doctor and a flight nurse. Prior to each mission, the experimenter input the relevant variables into the SAFE system to arrive at a risk assessment score. The pilots were not apprised of this score. Following each mission, the pilot was debriefed by the experimenter. In addition, pilots were asked to rate the risk of the mission just flown (segment by segment) and their subjective workload (full mission) using the NASA-Task Load Index (TLX) rating scale (Hart and Staveland, 1987). These two dependent measures were compared to the risk prediction provided by SAFE.

3. RESULTS

To compare scores on the three different scales, the scores were normalized and z-scores used in subsequent comparisons. The correlation matrix comparing SAFE predictions, risk ratings, and workload ratings is shown in Table 4. None of the correlations were significant.

Table 4. Correlation Matrix of SAFE, TLX, and Risk Ratings

	SAFE	TLX	Risk
SAFE	1.00		
TLX	0.16	1.00	
Risk	-0.03	0.18	1.00

The missions were divided into three categories typical of the EMS industry: (1) hospital to hospital transfers, (2) pre-scouted sites, and (3) unfamiliar scenes. The SAFE predictions were then correlated with the TLX ratings for each of the three mission types. These data are presented in Table 5. The starred correlation is significant at $p < .05$.

Table 5. SAFE predictions and TLX ratings correlations by mission type

Mission	Correlation
Hospital-Hospital Transfer	0.55*
Pick-up at Pre-scouted Site	0.18
Pick-up at Unfamiliar Scene	-0.37

4. DISCUSSION

An examination of the correlation matrix presented in table 4, suggests that SAFE predictions bore very little resemblance to the ratings of either risk or workload. However, as Table 5 shows, when the data are analyzed by mission type, SAFE scores correlate significantly with mission workload scores for hospital-to-hospital transfers. This difference in mission type will be addressed later. The risk assessments given by the pilots, however, continued to be unrelated to SAFE predictions.

Obtaining ratings of risk from the pilots proved to be difficult. Whether this is due to the existing climate of negative publicity or if the term "risk" was a poor choice of words is not clear. However, the pilots made comments such as, "There is no risk, otherwise I wouldn't take the flight", clearly casting doubt on the utility of the measure. The pilots seemed much more comfortable discussing workload. They seemed willing to accept that all missions had at least some degree of workload, and were willing to provide a range of ratings from high to low. The data analysis also pointed to the workload ratings as the most useful measure for testing the SAFE predictions. In addition, this method of assessing the difficulty of missions, and the impact of task requirements has been well established in many other applications and environments.

It is not surprising that the ability of SAFE to predict workload was ordered by mission type. On a hospital-to-hospital transfer, the pilot knows exactly where he is going, there is a landing pad, the ground personnel are trained for patient ingress and egress to the helicopter, and there are fewer surprises than in other mission types. In contrast, a pre-scouted site may have become overgrown, not been used in a while, or ground personnel may not be trained in helicopter operations. Further, with unfamiliar scene operations, there are a several unknown factors: (1) The pilot has never been to this exact scene, (2) It may be difficult to find; navigation aids will get the pilot to the general area, but the specific scene may be elusive, (3) Ground personnel may or may not be trained in helicopter operations. Thus, the predictability of these missions decreases as does SAFE's ability to predict risk profiles. SAFE does incorporate these factors into its computation, but only as they are known at the outset of the mission. For example, a scene pick-up may be predicted to have high risk at the beginning of the mission, but upon arrival the scene may have a good landing area with trained ground personnel, therefore the actual risk of the mission is low. For scene missions, those conditions are much more variable and impossible to know at the beginning of the mission.

4.1 Current Efforts-ASRS

The Aviation Safety Reporting System (ASRS) is operated by NASA with funding from the FAA. It is designed to collect more information about aviation incidents than was previously available. Following an aviation incident, a pilot (or other aviation personnel) can submit an anonymous report to ASRS and receive limited immunity from prosecution. ASRS compiles, and analyzes this data in an effort to spot hazardous trends and make recommendations before such incidents become accidents. Recently, the ASRS has publicized this service to the EMS community and solicited reports (Dodd, 1991). In an effort to evaluate the SAFE system with more data covering a wider range of mission types, and geographic regions, an ASRS call-back system was instituted. After each incident is reported, an analyst from ASRS will contact the reporter and conduct a detailed interview. This information will then be input into the SAFE system to determine if a high risk mission would have been predicted. It is hoped that this will strengthen and improve the SAFE system, as well as highlight continuing problem areas in EMS operations.

4.2 Current Efforts-Customized Knowledge-Base

Currently, efforts are underway to develop a version of SAFE that will build a customized knowledge-base for each EMS operator. The system will start with the initial knowledge-base developed in this study. After each mission, the pilot will answer a series of questions posed by SAFE. These will include ratings of workload and risk to refine the predictions of the system for this operator, but will also include specific queries about the route of the mission, any new wires, towers, or other man-made objects that were observed, etc. A knowledge-base will be developed that is adapted to and tailored for that operation and area. For example, SAFE will base predictions upon specific sites (not just site missions in general); it can take into account who the pilot is, and the last time they took a mission in this area, and update the pilot on any problems encountered in that area. The proposal for this version of SAFE is a finalist for the American Technology Initiative Program which sponsors joint research between NASA and private companies. If selected, this would accelerate the completion of this version of SAFE. A field test of this system is planned at one or more EMS operators.

4.3 Current Efforts-General Aviation

Discussions are underway with the Federal Aviation Administration (FAA) and the Center for Applied Human Factors in Aviation (CAHFA) to develop a risk assessment system such as SAFE for general aviation. One suggestion is that the system might include a computer link to automatized weather services, such as the Direct User Access Terminal (DUAT). In addition, it might be tailored for each pilot, (e.g., each pilot would input a disk to the system that contains current hours, ratings, etc., a sort of an electronic log book) based upon this information, in conjunction with the weather, and route information, the system will be able to give the pilot a clearer picture of the risks and issues involved in undertaking the proposed flight. The development of this system is still in the planning stages.

CONCLUSION

Human error is the largest single cause of aviation incidents and accidents. These types of risk assessment systems, then, represent an attempt to address that problem. By incorporating various data sources and taking advantage of the availability of personal computers, these systems promise to be an important aid to aviation safety.

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CORRELATIONS BETWEEN ENGINEERING, MEDICAL AND BEHAVIOURAL ASPECTS IN FIRE-RELATED AIRCRAFT ACCIDENTS

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SUMMARY

An overview is given over the present situation in aircraft fire safety as it can be derived from the 73rd AGARD-PEP-Meeting devoted to this subject in 1989. It is characterised by increasing interaction between engineering and medical/behavioural aspects. A scenario for aircraft cabin fires is first developped showing that survival times both from the technical and medical point of view are of the same order of magnitude. Although fire-hardening has contributed much to increased survival times the prospects for further progress from this side diminish. Improvements are expected from improved conditions for emergency evacuations and from occupant protection systems. Modelling studies both on engineering and medical problems are increasingly applied to fire-related problems. The use of water spray systems and smoke hoods are discussed in the paper as well as studies on passenger behaviour during evacuations. The combination of medical, behavioural and engineering expertise can be used to promote and optimise passenger protection in fire-related aircraft accidents.

1. INTRODUCTION

Aircraft accidents involving the development of -sometimes- catastrophic fires cannot be completely eliminated from aircraft operations. Therefore, it is the duty of the aerospace engineering community to take all preventive measures in order to minimise the consequences of such accidents. This is a truely interdisciplinary task insofar as -besides the classical fields of aircraft and aero engine design and operation- it does involve also aeromedical and psychological effects of human beings which are by fate thrown into such accidents.

AGARD's Propulsion and Energetics Panel is looking after the implications and consequences of aircraft fire safety since many years. One of its former working groups devoted to that subject, profitted a great deal from participation of members of the Aerospace Medical Panel. In 1989, the 73rd PEP-Meeting (1) was held on Aircraft Fire Safety, for which the present author served as the Programme Committee Chairman. More than 1/3 of that meeting was devoted to lectures on questions of survival times, passenger behaviour in emergency situations, crew training, as well as to passenger breathing equipment. These subjects have of course strong medical and behaviouristic interrelationships to the technical aspects of fire-related aircraft accidents. Therefore, very lively discussions and exchange of opinions developped among the meeting participants representing the related professional disciplines. When the Aerospace Medical Panel announced its present meeting on Aircraft Accidents, PEP solicited to present some thoughts and results on the correlations between engineering aspects on one hand, and medical and behaviouristic problems of fire-related accidents on the other hand, as they evolved from the 1989-PEP-Meeting on Aircraft Fire Safety.

Nearly three years have elapsed since the above mentioned PEP-Meeting was held, and surely, related research and development work went on in the mean time. However, the basic situation in aircraft fire safety changes only slowly; hence, one can assume that the principal findings and lessons to be learnt from that meeting are still valid. The present paper tries to give a summarising overview over the interdisciplinary correlations between the various aspects of fire-related accidents, as they can be derived from the last PEP-Meeting on Aircraft Fire Safety.

2. RECENT DEVELOPMENTS IN AIRCRAFT FIRE SAFETY

Work towards improved flight safety includes work towards improved survival chances of passengers and crew in fire-related aircraft accidents. The guidelines for such work are derived from accident evaluations from experimental investigations into situations during fire on board of aircraft, such as full-scale cabin fire tests, as well as from increased use of theoretical modelling of the various aspects of fire-related accidents. Particularly, the thorough evaluation of such accidents is directed mainly towards finding-out what safety deficiencies exist in aviation (2), and all of the three above mentioned sources of information are then used to try to eliminate or at least to reduce those safety deficiencies.

Statistical accident evaluations have shown that the probability for accidents to occur has diminished considerably in the past decades of aviation; however, the percentage of persons killed in fire-related accidents has remained fairly constant, at about 15 to 16 % over the past 30 years (3). Other information states about 23 % for that rate (4). These figures show that, on one hand, fire is still a major threat to life in aircraft accidents. On the other hand, careful comparisons of the specific conditions of the individual accidents lead to the conclusion, that there is still additional margin for the improvement of survival chances.

During the last decade a large number of full-scale cabin fire tests have been carried out in the US (5), in the UK (6) and in Germany (7), using fully-equipped aircraft fuselage sections or mock-ups in order to study the development of environmental conditions in cabin fires, particularly their time history. Together with accident evaluations, the results of these experiments allow to derive a general fire scenario on which to base future efforts for improvement of survival chances. Of course, there are differences between in-flight cabin fires and post-crash cabin fires; however, once an open fire is initiated in an aircraft cabin the path of its development is very similar for these two general categories of fire-related accidents.

3. FIRE SCENARIO AND SURVIVAL TIMES

The fire scenario is illustrated by fig. 1. It consists of three branches, the left-hand branch of which is of a pure technical nature. After the initiation of an open fire within the aircraft cabin, heat, smoke and toxic gases are produced. The latter is due to pyrolysis reactions in the burning material. Smoke and toxic gases consist of soot and partially burnt hydrocarbons, carbon monoxide, CO, hydrochloric acid, HCl, fluorine and cyanide compounds, such as HF and HCN, acrolein, etc., depending on the nature of the burning material. At first, the rise of temperature and CO-concentration is rather slow, as can be seen from fig. 2, which is taken from the DFVLR full-scale test (7). On the other hand, the HCl-concentration is developping rather fast already during the second minute of the test. At the same time, visibility degrades very rapidly, reaching light transmission values of about 20 to 30 % at 1.1 m above the floor towards the end of the second minute (fig. 3). Within the third minute the so-called flash-over occurs, a phenomenon which is characterised by a very rapid rise of temperature and toxic gas concentrations to levels which can no longer be sustained by human beings. Marking the end of the survival time from the technical point of view, flash-over is mainly caused by the fact that the temperature of the cabin interior materials has risen to a value which allows a rapid propagation of the fire throughout the whole cabin (8).

In the case of post-crash external fires some differences exist with respect to the time history of the environmental conditions in the cabin, depending on the specific circumstances of the crash. There may be cases where some more time is available until burn-through of the fuselage occurs and the fire enters the cabin. However, external fires can considerably threaten or even prevent a safe evacuation of the occupants.

Parallel to these engineering aspects of the fire scenario survival modelling studies have been carried out on the time to incapacitation due to the adverse environmental conditions in cabin fires. D.A. Purser has developped a mathematicel model for the estimation of hazards due to the exposure to toxic and irritant gases, smoke and heat (9). The model is based on the comparison between the product of the concentration of a noxious substance and exposure time and its effective lethal dose. Medical test data on lethal doses as well as post-crash fire test data on the time history of the concentrations have been used to establish the model. The main results are that in the first two minutes severe irritations of eyes and respiratory tracts caused by HCl and HF would impede the escape of persons. After the second minute interactions are strong enough to inhibit or prevent an escape. After the third minute incapacitations due to skin burns, loss of consciousness or visual obscuration is very likely to happen. This marks the end of the survival time in the fire scenario from the medical point of view.

A third branch of the fire scenario relates the chances for a successful emergency evacuation of the occupants to their behaviour under severe threat to their lives. Evidence from aircraft accidents, as well as from building fires and earthquakes show that in such situations people react very frightened and competitive in order to survive. This makes an orderly evacuation of all passengers very difficult, particularly in an environment of nearly zero visibility and where there are many obstacles, like seats, bulkheads or scattered hand-baggage. Therefore the chances for evacuation are severely impaired.

In recent years tests have been initiated in the UK in order to study the behavioural aspects of people during emergency evacuations. In one of the test series (10) a competitive element by incentive payments has been introduced, whereas by another test series the use of passenger breathing equipment was studied under visibility conditions which were reduced by smoke(11). The development of such test methods is still at the beginning, and one can expect that they will yield additional information for the improvement of survival chances in fire-related aircraft accidents.

The facts described above and put together in the fire scenario, fig. 1, allow the following conclusions:

- Although specific conditions can have great influence on the situation in aircraft cabin fires the basic scenario is very similar; this fixes the ultimate survival chances of occupants.

- The available survival times both from the technical and the medical point of view are not too different; in cabin fires they are limited in the order of 2 - 3 minutes.

- During this time conditions in the cabin worsen rapidly and continuously due to decreasing visibility and increasing effects of heat and toxic gases.

- The competitive behaviour of people in highly stress-loaded situations makes an orderly evacuation under adverse spatial conditions very difficult.

A real increase of survival chances can only be achieved by interdisciplinary efforts in which the engineering experts and the medical, psychological experts combine their knowledge.

4. POSSIBLE WAYS FOR INCREASED SURVIVAL CHANCES

The directions for work towards enhanced survival chances can be derived from fig. 1. Particularly, the 73rd PEP-Meeting on Aircraft Fire Safety has emphasised the following routes which involve also medical and behavioural efforts (fig. 4):

- Increase of survival times by better materials and design (fire hardening).

- Introduction of passenger protection systems during emergency evacuations.

- Improved spatial conditions for emergency evacuations by suitable cabin interior design.

Some prospects for future work into these directions will be discussed in the following as well as related questions, placing emphasis with the correlations between engineering and medical/behavioural aspects.

4.1. INCREASED SURVIVAL TIMES BY BETTER MATERIALS AND DESIGN

Promoted particularly by the US Federal Aviation Agency new materials have been developped which show improved fire resistance. Here, materials for fire-blocking layers of seat cushions and other upholstery are to be mentioned which can delay the propagation of flames and exhibit lower weight loss during the combustion. Their use is now mandatory after the issue of corresponding rules by the FAA. Also new materials which show lower heat release rates are now available for side wall and ceiling panels in aircraft cabins. Previous tests had shown that the time to flash-over depended mainly on the rate of heat release of the burning panels. It was also found that small changes in heat release can result in comparatively large delays of flash-over. Consequently, the selection of materials for interior panels is now based on heat release properties. After intensive testing materials have been found, particularly based on phenolic resins and fibre glass, which can delay the flash-over by about 1 - 2 minutes as compared to earlier materials. Whether this delay can be completely turned into prolongated survival times in practice depends on the specific condition of the fire. Similar efforts are now going on with respect to cargo bay materials and for improved insulation of aircraft cabins in external fires (Refs. 12, 13, 14).

Regulations which limit the production of smoke and toxic gases during materials fire tests have not yet been issued. However, it may be assumed that materials with changed chemical composition may also produce different amounts of noxious substances. In their work towards improved cabin materials industry of course measures toxic gas concentrations and their composition (14). However, the results of such measurements should be made available on a much wider scale than up to now in order to use them in medical modelling studies for the time to incapacitation. Thus, the application of models like that of D.A. Purser (9) could help to assess different materials with respect to their fire-related production of smoke and noxious gases yielding additional information for the selection of the most suitable cabin materials.

However, at the 73rd PEP-Meeting it was also stated that the potential for further progress in fire-resistant light weight materials seems to be nearly exhausted (15). Therefore, besides an eventual use of more metallic materials, future improvements for increase of survival times should be more expected from systems for active and passive occupant protection during emergency evacuations.

4.2. INCREASE OF SURVIVAL CHANCES BY OCCUPANT PROTECTION SYSTEMS

Hopes for the improvement of survival chances centre presently around the use of water spray systems, reversed venting systems as well as on the use of smoke hoods which will be discussed in the following paragraph. The first two ideas are intended to generate a passive protection by improving the environmental condition in the cabin.

Water spray systems for aircraft cabins have already been developped and investigated in actual tests with external fir · (16). Fitted to the cabin interior they have proved their capability to delay the burn-through of fuselages in external fires, to cool down burning and smouldering interior materials and hence to slow down the production of heat, smoke and toxic gases. Moreover they can help to clean the cabin atmosphere from such substances. Particularly the latter achievement could increase the time to incapacitation as well as facilitate emergency evacuations by improved visibility. The tests carried under external fire conditions with a narrow-body aircraft fuselage so far have shown that there is a good potential to delay a burn-through and the build-up of a noxious atmosphere inside the cabin by times ranging up to several minutes (16), if there is enough spray water available.

However, more research and development work is needed in order to optimise the design, installation and use of such systems. This includes also its application to wide-body aircraft. Parallel to these aspects, also medical and environmental questions have to be addressed, such as the effect on the occupants of the aspiration of a mixture of water spray droplets, dissolved toxic gases and smoke particles or the effect of additives, which are needed for the increased absorption of carbon monoxide or for lowering the freezing point of the spray water in its on-board tank. Finally, mathematical modelling has to be applied to assess the effectiveness of water spray systems both from the technical and medical point of view.

Considering the large number of open questions it seems to be that water spray systems would be only a long-term solution, particularly, as their on-board installation would be ecenomic only for new aircraft. It has also to be recognised that improved fire safety by an on-board water supply can only be obtained by a reduction in payload.

Another possible approach to cabin protection in fire-related accidents was observed when modelling aerodynamic conditions in cabin fires (17). It was found that reversing the airflow direction in the venting system of the aircraft had a beneficial effect on the temperature distribution inside the cabin. Reversed does mean here that fresh air is injected from the cabin floor and hot gases are extracted by the ceiling vents. Additional modelling work was intended in order to include combustion and heat effects into the study, which was purely aerodynamic, hitherto (17). Further investigations must show whether this is actually a viable contribution to increase the survival chances.

4.3. IMPROVEMENT OF CONDITIONS FOR SUCCESSFUL EMERGENCY EVACUATIONS

The chances for survival by emergency evacuations depend to a large degree on the geometrical and spatial boundary conditions of the cabin, on the information and the overview which the crew has on the specific fire situation, as well as on the behaviour of the passengers in a highly stress-loaded situation, facts which are partly interrelated. Accident investigations showed that the flight crew often lacks vital information on the fire situation inside or outside the aircraft e.g. in post-crash fires, which might lead to wrong decisions. Improved crew training can only partly contribute to solve such problems. This training should include also information on human factors, like passenger behaviour in emergency situations. Other problem areas which need input from behavioural experts are, for example, how to communicate the right instructions to the occupants in chaotic situations or how to identify emergency exits under reduced visibility conditions. Particularly, studies on passenger behaviour in such situations can help to identify possibilities for the improvement of evacuations. Here again, the UK was a forerunner in carrying out tests to study the effects of passenger behaviour on flow rates during emergency evacuations.

Two specific aspects have been studied, namely different geometric constraints of the escape way (10), and the use of breathing equipment, i.e. smoke hoods (11). The first mentioned study at Cranfield investigated the effect of different arrangements of cabin furniture, i.e. varying seating pitch and galley width, on evacuation time from a fully equipped aircraft fuselage, introducing an element of competition between the test persons by incentive payments. These tests showed that actually similarities existed with respect to real emergency situations insofar as heavy blockage of escape ways and around exits could be observed. However, larger variations of behaviour from trial to trial were also found resulting in corresponding variations of evacuation times. It was concluded that more tests are needed in order to achieve statistically reliable results. Likewise, the test conditions should be revised introducing further elements of stress, for example by using smoke.

The second study at the CAA Fire School has been carried out in order to learn about the effect of smoke and of wearing smoke hoods on evacuation time. In a comparatively small number of evacuations different conditions, clear air and smoke, with and without smoke hoods, were investigated using usual seating arrangement in a narrow-body fuselage. White theatrical smoke, accepted by the Medical Ethics Committee, was introduced as an element of stress. Besides evacuation time strongly depending on the location of the seats within the cabin, it was found that the presence of smoke as well as the donning and wearing smoke hoods both prolonged the evacuation time. The combined effect was however less than the sum of the individual time increments in the two former cases. A further observation which seems to be significant was that in the case of wearing smoke hoods the evacuation took place in a more orderly fashion than without smoke hoods. It was therefore concluded that the smoke hoods apparently generated a feeling of being protected to some extent.

Tests of the k nd described above warrant further exploration of these subjects in which also the aerospace medical community should be very interested. Particularly, the case of wearing smoke hoods during emergency evacuations is still open and surely needs further clarification. Other questions to be addressed concerning these tests are, what are suitable methods for making test conditions more realistic and how far can one go into that direction without violating ethic laws.

5. CONCLUSIONS AND RECOMMENDATIONS

The evaluation of AGARD-PEP's 73rd Meeting on Aircraft Fire Safety shows that further progress towards improved survival chances of occupants in fire-related accidents demands for activities in which medical and behavioural questions gain increasing importance. This concerns the development of possibilities for active and passive protection of aircraft occupants as well as the improvements of conditions for their successful egress from aircraft on fire. The tasks of medical and behavioural experts involved in such activities are to investigate the effectiveness and compatibility of new technical solutions to the mentioned problems with respect to the consequences for the occupants as well as to participate in efforts to generate more realistic testing methods.

It is therefore desirable that the formerly well-established cooperation of the Aerospace Medical Panel and the Propulsion and Energetics Panel in aircraft fire safety is continued by setting-up a new Inter-Panel Working Group, the tasks of which should be :

- to assess the survival chances from fire-related aircraft accidents, considering recent progress in fire-hardening, occupant protection systems, management of fire situations, including emergency evacuations, fire fighting techniques, and modelling of fire situations with respect to survival chances, and
- to identify needs for further research and development work towards improved fire safety in aviation.

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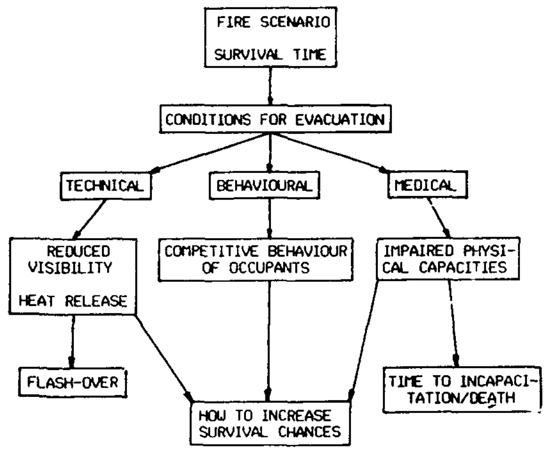

Fig. 1 Schematic representation of correlations between engineering, behavioural and medical aspects in fire-related aircraft accidents.

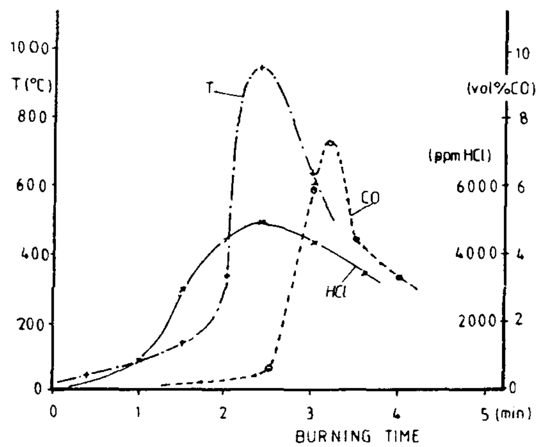

Fig. 2 Time history of temperature T and concentrations of carbon monoxide, CO, and hydrochloric acid, HCl, during a full-scale cabin fire test, measured at 2 m distance from ignition source and 1.6 m above cabin floor, (7).
Peak concentrations of some toxic gases during test : HCl 5400 ppm, HBr 300 ppm, HF 500 ppm, HCN 2400 ppm.

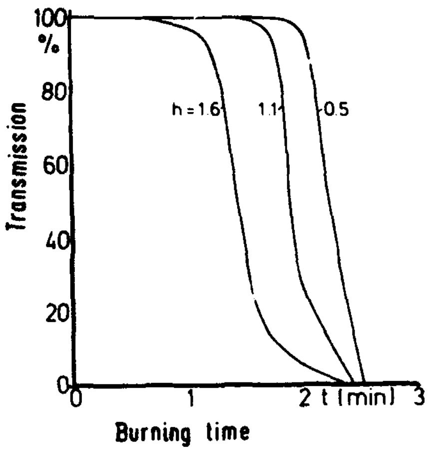

Fig. 3 Reduction of visibility with burning time as measured by transmission of light in a cabin fire at different heights above floor, (7).
100 % transmission = clear air.

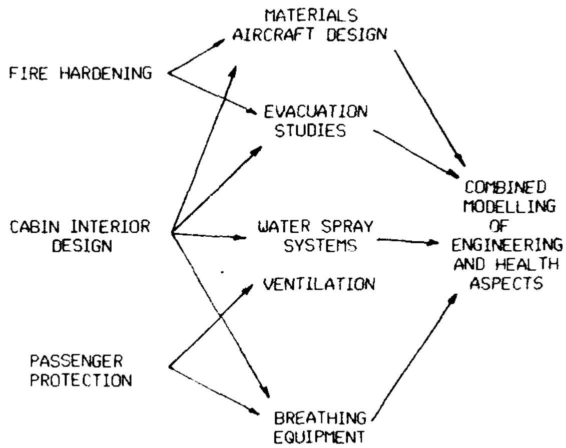

Fig. 4 Future trends for improved survival chances in aircraft cabin fires.

INCENDIES A BORD DES AERONEFS : RISQUE TOXICOLOGIQUE EN VOL

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RESUME

Lors d'incendies à bord des aéronefs, l'intoxication par les produits de thermolyse des matériaux utilisés dans l'aménagement de la cabine représente un risque majeur. Pour évaluer le risque toxique lors d'incendies en vol, il est nécessaire de prendre en compte non seulement la ventilation mais aussi la pression de la cabine, qui peut varier entre 1000 et 750, voire 700 hPa. Un modèle feu original a été mis au point, permettant d'étudier, dans des conditions de ventilation représentatives de celles d'un aéronef, l'influence de la pression sur la thermolyse de divers matériaux. La thermolyse a été envisagée sur le plan physicochimique et toxicologique, la souris étant choisie comme modèle animal. L'étude a montré que le risque toxique varie considérablement en fonction du matériau considéré. Par ailleurs, dans ces conditions expérimentales, la baisse de pression barométrique de 1000 à 700 hPa a peu modifié les caractéristiques physico-chimiques de la thermolyse de la plupart des matériaux étudiés. En revanche cette baisse de pression a engendré le plus souvent une augmentation très significative de la toxicité du mélange gazeux généré, dans lequel le monoxyde de carbone et/ou l'acide cyanhydrique ont une part prépondérante.

INTRODUCTION

D'après les données de la Federal Aviation Administration (1), 74 accidents avec feu à bord se sont produits dans l'aviation commerciale entre 1966 et 1988, faisant, parmi les 8623 passagers ou membres d'équipage, 2688 victimes. Parmi ces accidents, au moins 17 ont été à l'origine d'un total d'environ 1000 décès directement liés au feu. Cela représente un pourcentage extrêmement faible au regard de l'ensemble des vols effectués durant cette période ; le risque ne peut être cependant négligé étant donnée l'extrême gravité d'un feu dans une enceinte confinée dont il est difficile de s'échapper rapidement. L'examen plus approfondi des causes de décès par le feu montre que, dans la grande majorité des cas, les passagers ont péri à la suite de l'inhalation de gaz et fumées toxiques. Aussi de nombreuses études ont-elles été entreprises dans le but de sélectionner les matériaux utilisés dans l'aménagement des cabines d'avion et de mettre en place ou d'améliorer les détecteurs de feu, les extincteurs et les cagoules antifumées.

Pour ce qui concerne les matériaux, il existe actuellement des normes internationales (FAR 25) concernant la tenue au feu, c'est à dire la vitesse de propagation des flammes au sein du matériau, ainsi que la densité des fumées émises. Ces normes ont été récemment complétées par un additif imposant l'utilisation de tissus barrière feu pour protéger les coussins en mousse des sièges (FAR 25.853b et c). Malheureusement, il n'existe actuellement pas de normes internationales concernant la toxicité des gaz libérés, bien que ce critère soit fondamental. En effet de nombreux matériaux dégagent des gaz très toxiques, c'est le cas en particulier de certains matériaux ignifugés. L'idéal serait donc d'établir un indice combiné de risque qui prendrait en compte tenue au feu, densité des fumées et toxicité des gaz émis. La difficulté réside actuellement dans le choix d'un modèle feu de laboratoire aussi réaliste que possible; en effet la thermolyse d'un matériau et le dégagement gazeux dépendent en particulier des géométries de la chambre de combustion et de l'échantillon ainsi que de l'apport d'oxygène. Par ailleurs le choix du modèle feu dépend de la situation à reproduire. Ainsi, dans plusieurs pays, les recherches ont essentiellement porté sur les risques liés aux incendies après crash, ceux-ci étant les plus fréquents. En revanche, en France, les recherches se sont orientées vers l'étude des incendies en vol, qui, quoique rares (4 accidents de 1966 à 1988), peuvent s'avérer particulièrement dramatiques. L'accident du Boeing 707 de la compagnie Varig à Saulx les Chartreux, le 11 Juillet 1973, en est une triste illustration. L'avion, en provenance de Rio de Janeiro, signala à la tour d'Orly, après un vol sans incident, un feu à bord. Ne pouvant rejoindre la piste, il fit un atterrissage d'urgence parfaitement réussi à 5 km. Pourtant 122 parmi les 134 occupants de l'avion avaient succombé à l'inhalation des gaz toxiques libérés lors de la thermolyse des matériaux plastiques d'aménagement de la cabine.

Dans le cadre des études d'incendies en vol, deux paramètres sont essentiels, il s'agit de la ventilation et de la pression de la cabine. Le premier paramètre a été pris en compte dans de nombreuses expérimentations (2), en revanche le deuxième ne semble pas avoir été considéré. Or l'altitude cabine d'un avion en conditions normales de vol commercial peut atteindre 8000 ft, ce qui correspond à une pression de 750 hPa (FAR 25.841). De plus, dans certaines procédures opérationnelles mises en oeuvre en cas d'incendie, l'altitude cabine peut être amenée à 10000 ft, ce qui correspond à une pression de 700 hPa, pour permettre une ouverture rapide des portes après équilibrage des pressions à l'intérieur et à l'extérieur de l'avion.

C'est pourquoi le Laboratoire de Médecine Aérospatiale, à la demande de la Direction des Recherches, Etudes et Techniques, a mis au point un modèle feu (3) qui permet :

- d'une part une étude physicochimique des produits de dégradation thermique, en altitude, de matériaux utilisés dans l'aménagement des cabines d'avion

- d'autre part l'étude de leur toxicité sur l'animal, la souris, lorsqu'ils sont inhalés en altitude.

PRESENTATION DE L'EXPERIMENTATION

1. Méthodologie

1.1. Matériel expérimental

Le modèle feu comporte une chambre de décomposition thermique, une chambre d'exposition des animaux et une pompe (photographie n°1).

Chacune des chambres est un cylindre en acier inoxydable de 96 dm^3 de volume s'ouvrant à l'une de ses extrémités par un couvercle, les deux cylindres communiquant entre eux par un tube spiralé de trois mètres de long servant d'échangeur thermique. La chambre de décomposition thermique est munie d'un dispositif d'entrée d'air qui permet de régler la pression à l'intérieur des caissons. La chambre d'exposition des animaux est reliée à une pompe qui assure dépression et ventilation.

La chambre de décomposition thermique comporte le porte-échantillon constitué d'un support métallique sur lequel repose une nacelle en quartz dans laquelle est placé l'échantillon à tester. Le module de chauffage est constitué de trois émetteurs infrarouge de 1000 W chacun placés de part et d'autre du porte-échantillon (photographie n°2). La chambre d'exposition des animaux est équipée de quatre cages recevant chacune un animal et intégrées dans un système de mesure d'incapacitation fondé sur l'activité d'exploration spontanée des animaux (photographie n°3).

Le matériel de mesure est constitué d'analyseurs de gaz et de capteurs permettant le suivi des paramètres physiques essentiels (température, débit, pression). Les oxydes de carbone et d'azote sont dosés en continu, par analyseurs infrarouge pour le monoxyde et le dioxyde de carbone, par analyseur fonctionnant sur le principe de la chimi-luminescence pour le monoxyde et le dioxyde d'azote. Les autres gaz sont dosés par tubes Draëger.

1.2. Protocole

L'étude a porté dans un premier temps sur la toxicité du monoxyde de carbone, gaz majeur dégagé lors des incendies. Elle a porté par ailleurs sur la thermolyse de divers matériaux utilisés dans l'aménagement des cabines d'avion, à savoir le peuplier (ce matériau, anciennement utilisé à bord des avions et ne dégageant en quantité importante que des oxydes de carbone, est considéré comme référence), deux types de laine A et B, un tissu Imidex, de la mousse polyuréthane (SABLE) et un tissu barrière feu (HEXCEL-GENIN). Pour le monoxyde de carbone et chacun des matériaux testés, les essais ont été effectués à deux niveaux de pression, 1000 et 700 hPa.

1.2.1. Etude de la toxicité du monoxyde de carbone (CO)

Après injection du monoxyde de carbone dans la chambre de thermolyse, l'homogénéisation a été réalisée en environ 2 minutes grâce à une pompe assurant la ventilation en circuit fermé entre les deux chambres. Les souris ont été exposées au gaz toxique durant 20 minutes.

A chaque niveau de pression, trois paramètres biologiques ont été mesurés: les temps d'incapacitation, la concentration létale 50 (Cl 50) et les taux de carboxyhémoglobine.

L'incapacitation est un paramètre essentiel en toxicologie (4) puisqu'elle entraîne l'impossibilité de fuir, sans aide extérieure, une ambiance toxique. Deux temps ont été déterminés, un premier temps d'incapacitation correspondant à la réduction de l'activité motrice spontanée et un temps d'incapacitation totale correspondant à l'immobilisation complète.

La Cl 50, exprimée en ppm (parties par million) et en mg/m^3 et déterminée sur des lots de 4 souris exposées, correspond à la concentration en monoxyde de carbone entraînant la mort de la moitié des animaux exposés durant une période de 20 minutes. Elle a été évaluée par la méthode des probits.

Par ailleurs des échantillons sanguins ont été recueillis sur les souris mortes, dès le retrait des animaux de l'ambiance toxique et au plus 10 minutes après la mort. Le pourcentage de carboxyhémoglobine a été évalué à partir du dosage du CO sanguin par chromatographie en phase gazeuse.

1.2.2. Etude de la thermolyse des matériaux

Le choix des conditions de ventilation et de pression dans le modèle feu a été motivé par la connaissance de ces paramètres dans les avions commerciaux, dans lesquels le circuit de climatisation et de pressurisation assure le renouvellement total de l'air de la cabine en environ 3.5 minutes et une pression cabine pouvant varier entre 1000 et 700 hPa.

Les essais ont donc été effectués avec un débit de ventilation de 55 dm^3/min, en circuit ouvert, à des pressions de 1000 et 700 hPa.

Pour chaque niveau de pression, il a été réalisé une montée progressive en température jusqu'à atteindre 700°C au niveau des résistances, suivie d'une régulation à cette température, l'ensemble de ces deux phases durant 15 minutes. Les résistances chauffantes ont alors été débranchées, le processus de thermolyse étant cependant étudié sur une durée totale de 30 minutes. Grâce à ce système de chauffage, le porte échantillon, vide, est porté à une température de 420°C en 8 minutes environ. Ce procédé de thermolyse paraît mieux correspondre aux conditions réelles d'un incendie que l'exposition d'un matériau à une température constante.

L'étude analytique a comporté l'évaluation du pourcentage de perte de poids de l'échantillon, la mesure de la densité des fumées et l'analyse des gaz.

L'étude toxicologique, faite sur la souris, a été abordée par la mesure des temps d'incapacitation et le calcul de la concentration létale 50, c'est à dire la concentration en matériau entraînant la mort de la moitié des animaux exposés aux produits de dégradation par thermolyse durant une période de 30 minutes à partir du branchement des résistances. Le plus classiquement, la concentration létale 50 est exprimée en poids de matériau engagé rapporté au volume d'air balayant l'enceinte de thermolyse ; il nous est apparu a priori plus réaliste de l'exprimer en poids de matériau rapporté au volume de l'enceinte.

2. Résultats

2.1. Etude de la toxicité du monoxyde de carbone

Les concentrations létales 50 exprimées en ppm et en mg/m^3 figurent dans le tableau 1.

Tableau 1: concentrations létales 50 du monoxyde de carbone

Ces résultats montrent que la Cl 50 (mg/m^3) à 700 hPa, exprimée sous forme de son pourcentage par rapport à la Cl 50 à 1000 hPa, est de 54 %.

Pour ce qui concerne les taux létaux de carboxyhémoglobine, les mesures ont été réalisées, pour chaque pression, sur les prélèvements sanguins de 8 souris exposées à des concentrations voisines de la Cl 50. La moyenne de ces 8 dosages est de 83.3 % (s = 10.9) à 1 000 hPa et de 82.1 % (s = 8.8) à 700 hPa.

2.2. Etude de la thermolyse des matériaux

2.2.1. Résultats de l'étude analytique

Les modifications de pression n'ont engendré, pour la plupart des matériaux, que des variations relativement faibles au niveau de la perte de poids, de la densité des fumées et du dégagement gazeux des échantillons. Seule la thermolyse de la laine B s'est trouvée très significativement modifiée par la dépression, si l'on considère l'ensemble des paramètres mesurés, avec un pourcentage de perte de poids et un dégagement d'oxydes de carbone et d'acide cyanhydrique notablement plus faibles. Nous noterons que le peuplier dégage essentiellement des oxydes de carbone tandis que les autres matériaux étudiés dégagent des oxydes de carbone, des oxydes d'azote et de l'acide cyanhydrique (Tableaux 2 et 3).

Les quantités de gaz toxiques (à l'exclusion du dioxyde de carbone) dégagées par la thermolyse d' échantillons de 10 g, calculées pour chaque matériau, sont présentées dans les tableaux 2 et 3, respectivement pour les pressions de 1000 hPa et 700 hPa. Les résultats paraissent sous forme de leur moyenne et écart type pour le monoxyde de carbone, les dosages ayant été effectués, pour chaque matériau, sur 10 à 20 échantillons ; en revanche l'analyse de l'acide cyanhydrique (HCN) et des oxydes d'azote (NO et NO_2) n'a porté que sur 1 à 2 échantillons.

Tableau 2 : Résultats analytiques à 1000 hPa (matériaux)

Tableau 3 : Résultats analytiques à 700 hPa (matériaux)

2.2.2. Résultats de l'étude toxicologique

Les résultats obtenus sur les temps d'incapacitation ne sont pas présentés étant donné que les variations observées en fonction du matériau et du niveau de pression sont relativement faibles pour des échantillons correspondant sensiblement à la concentration létale 50.

En revanche les valeurs des concentrations létales 50 sont très variables et figurent dans le tableau 4 ; elles sont exprimées en quantité de matériau engagé rapportée au volume de la chambre de thermolyse :

Tableau 4 : Concentrations létales 50 à 1000 et 700 hPa (matériaux)

Si l'on exprime la Cl 50 à 700 hPa sous forme de son pourcentage par rapport à la Cl 50 à 1000 hPa, les résultats pour chaque matériau sont les suivants :

- peuplier : 60 %
- mousse polyuréthane : 60 %
- tissu imidex : 64 %
- laine A : 76 %
- laine B : 96 %
- tissu barrière feu : 68 %

DISCUSSION

1. Comparaison des divers matériaux

Cette étude montre que le comportement au feu, pour un niveau de pression donné, peut varier considérablement d'un matériau à l'autre, que l'on considère les paramètres analytiques ou les paramètres toxicologiques. Ainsi, pour les matériaux envisagés, la concentration létale 50 à 1 000 hPa varie de 614.4 g/m^3 pour le peuplier à 19.7 g/m^3 pour le tissu barrière feu. Il existe une bonne corrélation entre les résultats de l'analyse toxicologique et les résultats de l'étude analytique. En effet, si l'on considère les quantités moyennes de gaz toxiques (monoxyde de carbone, acide cyanhydrique, monoxyde d'azote), ainsi que les concentrations maximales rapportées à 10 grammes de matériau engagés, on constate qu'elles sont en relation avec l'ordre de toxicité croissante des matériaux :

peuplier < mousse polyuréthane < tissu imidex < laine A < laine B < tissu barrière feu).

2. Influence de la pression sur la thermolyse des matériaux et la toxicité des gaz dégagés

Si l'on exclut le cas de la laine B pour laquelle les dégagements de monoxyde de carbone et d'acide cyanhydrique semblent nettement moindres lorsque la pression diminue, il ressort de ces études que la diminution de la pression barométrique de 1000 à 700 hPa, malgré la baisse importante de pression partielle en oxygène qu'elle entraîne, modifie peu la thermolyse des matériaux. Ceci s'explique a priori par le fait que l'apport continu en oxygène, grâce à une ventilation poussée, est suffisant pour que la dépression ne soit pas un facteur limitant la thermolyse. Mais ceci n'est naturellement vrai que dans nos conditions expérimentales particulières où les poids maximaux d'échantillons engagés n'excèdent que peu les poids d'échantillons correspondant à la Cl 50. Toutefois il ne fait guère de doute que, pour des quantités très importantes de matériau, la dépression deviendrait un facteur limitant de la thermolyse pour des valeurs usuelles de la ventilation.

D'un point de vue toxicologique, pour une même quantité de gaz toxiques dégagée, l'expérimentation montre que, pour cinq des matériaux étudiés, la dépression majore considérablement la toxicité sur l'animal. Cette influence de la dépression est également observée avec le monoxyde de carbone pour lequel la Cl 50 (mg/m^3), pour une exposition de 20 minutes, est divisée par 2 environ lorsque la pression barométrique passe de 1000 à 700 hPa. En ce qui concerne l'acide cyanhydrique, une étude effectuée sur la souris (5) montre que, pour un temps d'exposition de 30 minutes à pression atmosphérique standard, la CL 50 est environ divisée par deux lorsque la pression partielle en oxygène passe de 210 hPa à 138 hPa, ce qui correspond aux pressions partielles en oxygène pour des pressions atmosphériques de respectivement 1000 et 660 hPa.

L'influence de l'altitude sur la toxicité du monoxyde de carbone et de l'acide cyanhydrique est cohérente avec le mode d'action toxique de ces deux gaz. En effet le monoxyde de carbone se combine de façon réversible à l'hémoglobine, pour laquelle il a une affinité très supérieure à celle de l'oxygène, et forme de la carboxyhémoglobine ; il réduit ainsi la quantité d'oxygène transportée par le sang sous forme d'oxyhémoglobine et limite de plus la libération de l'oxygène au niveau des tissus en déplaçant vers la gauche la courbe de dissociation de l'hémoglobine. L'intensité de l'intoxication est sensiblement fonction du pourcentage de carboxyhémoglobine formée. Il est également connu que le monoxyde de carbone gagne les territoires extravasculaires. Il semble par ailleurs avoir un effet toxique direct sur les tissus en se liant à la cytochrome oxydase (6). La baisse de pression barométrique et par conséquent la baisse de pression partielle en oxygène dans l'air inspiré entraîne une diminution de la pression partielle artérielle en oxygène. Or le pourcentage de carboxyhémoglobine, d'après l'équation de Haldane, est proportionnel, à l'équilibre, au rapport des pressions partielles artérielles en oxygène et en monoxyde de carbone. Ceci explique au moins en partie l'augmentation de toxicité du monoxyde de carbone lorsque la pression barométrique décroît de 1000 à 700 hPa, la mort survenant pour des pourcentages en carboxyhémoglobine comparables dans les deux cas.

Pour ce qui concerne l'acide cyanhydrique, il agit en se combinant à la cytochrome oxydase, empêchant ou limitant l'utilisation par les tissus de l'oxygène transporté par le sang, en particulier au niveau du centre respiratoire. Expérimentalement, il est démontré que la baisse de pression partielle en oxygène dans l'air inspiré augmente les effets toxiques de l'acide cyanhydrique. D'après certains auteurs (7), cette augmentation de toxicité serait due à une affinité accrue de l'acide cyanhydrique pour la cytochrome oxydase.

L'influence de l'hypoxie sur la toxicité des autres gaz susceptibles de se dégager lors d'incendies, en particulier les oxydes d'azote et l'acide chlorhydrique, n'est pas connue. Il est cependant permis de supposer que la toxicité du monoxyde d'azote est également influencée par l'altitude, étant donné que ce gaz a pour cible, comme le monoxyde de carbone, l'hémoglobine. Il provoque la formation de méthémoglobine non fonctionnelle.

Les résultats obtenus sur les gaz purs permettent d'interpréter les données recueillies lors de l'étude des matériaux. Ceux-ci dégagent du monoxyde de carbone et/ou des oxydes d'azote et de l'acide cyanhydrique. Il est donc normal de constater que la toxicité de leurs produits de thermolyse est accrue lorsque la pression barométrique diminue, dans la mesure où leur thermolyse n'est pas modifiée. Il faut cependant noter que, lors de la dégradation thermique des matériaux, les concentrations en gaz toxiques étant très variables en fonction du temps, les conditions d'intoxication ne peuvent être directement comparées aux conditions d'intoxication par des gaz purs à concentrations constantes. Par ailleurs, cette dégradation, s'accompagnant d'un dégagement important de dioxyde de carbone, est à l'origine par elle-même d'une diminution de la pression partielle en oxygène dans l'ambiance.

3. Toxicité pour l'homme

Les effets toxiques des produits de thermolyse étant mis en évidence sur l'animal, il faut bien évidemment s'interroger sur la possibilité d'extrapoler ces résultats à l'homme. La souris est considérée comme un bon modèle pour les intoxications par voie respiratoire. D'après les données de la littérature (9,10), si l'on considère le monoxyde de carbone et l'acide cyanhydrique, il semble que les concentrations létales chez l'homme, pour des temps d'exposition de 30 minutes, ne soient pas extrêmement différentes de celles observées chez la souris, l'homme restant cependant moins sensible au monoxyde de carbone et plus sensible à l'acide cyanhydrique. Ceci s'expliquerait en partie, pour le monoxyde de carbone, par le fait que les cinétiques de l'intoxication sont très différentes, l'équilibre, pour des concentrations de l'ordre de 150 à 1100 ppm, étant probablement atteint en moins de 30 minutes chez la souris et en environ 2 à 5 heures pour l'homme (11, 12).

CONCLUSION

En conclusion, les études que nous avons menées ont permis une approche des risques engendrés, en cas d'incendie à bord d'un avion, par la thermolyse de divers matériaux utilisés dans l'aménagement des cabines.

Les avions étant soumis en vol à des conditions normalisées de ventilation et de pression, nous nous sommes attachés à recréer, dans un modèle feu de laboratoire, les conditions de ventilation et à étudier l'influence de la pression sur les phénomènes de thermolyse et les risques toxiques. La souris a été choisie comme modèle animal.

Dans nos conditions expérimentales, la baisse de pression barométrique de 1000 à 700 hPa n'a pas modifié très significativement la thermolyse pour cinq des six matériaux étudiés (peuplier, mousse de polyuréthane, tissu imidex, laine A, tissu barrière feu). En revanche, pour ces cinq matériaux, la baisse de pression a engendré une augmentation très significative de la toxicité du mélange de gaz toxiques dégagé lors de la thermolyse, mélange dans lequel le monoxyde de carbone et/ou l'acide cyanhydrique ont une part prépondérante. Le sixième matériau (laine B), qui n'a pas répondu comme le précédent, montre à quel point des matériaux apparemment comparables, comme deux laines, peuvent avoir des comportements très différents.

Ces résultats montrent donc l'intérêt de prendre en compte la pression dans l'étude des risques engendrés par un incendie en vol et mettent également en évidence combien il est difficile de maîtriser l'ensemble des paramètres intervenant, en situation réelle, dans ces phénomènes.

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Tableau 1 : concentrations létales 50 du monoxyde de carbone

Pression (hPa)	CL 50 (ppm)	CL 50 (mg/m^3)
1000	5708 (s = 190)	6537 (s = 218)
700	4369 (s = 185)	3502 (s = 148)

Tableau 2 : Résultats analytiques à 1000 hPa (matériaux)

Matériau	CO (g)	HCN (mg)	NO (mg)	NO_2 (mg)
Peuplier	1 (s = 0.15)	/	/	/
Mousse PU	2.29 (s = 0.39)	87	10	8.6
Imidex	2.33 (s = 0.40)	118	23	79
Laine A	2.62 (s = 0.29)	231	50	132
Laine B	3.61 (s = 0.66)	640	64	131
Barrière feu	5.23 (s = 0.93)	855	92	116

Tableau 3 : Résultats analytiques à 700 hPa (matériaux)

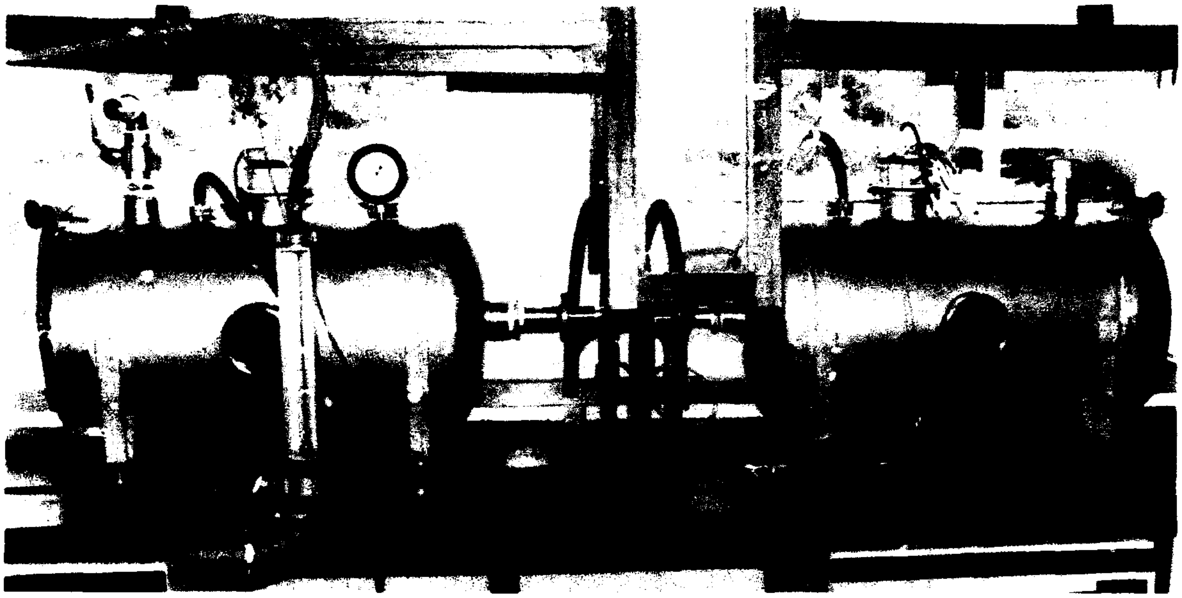
Matériau	CO (g)	HCN (mg)	NO (mg)	NO_2 (mg)
Peuplier	1.02 (s = 0.18)	/	/	/
Mousse PU	2.62 (s = 0.81)	72	13	5.1
Imidex	1.78 (s = 0.20)	86	19	54
Laine A	1.87 (s = 0.14)	-	-	-
Laine B	2.30 (s = 0.57)	280	54	180
Barrière feu	4.17 (s = 0.38)	536	85	164

Tableau 4 : Concentrations létales 50 à 1000 et 700 hPa (matériaux)

Matériau	CL 50 (g/m^3) à 1000 hPa	CL 50 (g/m^3) à 700 hPa
Peuplier	614.4 (s = 39.3)	370.6 (s = 8.4)
Mousse PU	133.6 (s = 2.1)	79.9 (s = 0.4)
Tissu imidex	95.7 (s = 4)	61.3 (s = 2.1)
Laine A	67.1 (s = 3.8)	51 (s = 2.9)
Laine B	25.1 (s = 0.1)	24 (s = 0.5)
Tissu barrière feu	19.7 (s = 0.8)	13.4 (s = 0.3)

PHOTOGRAPHIE N° 1

INSTALLATION D'ESSAIS



De gauche à droite : la chambre d'exposition des animaux, le tuyau de raccordement en spirale et la chambre de décomposition thermique

PHOTOGRAPHIE N° 2

CHAMBRE DE DECOMPOSITION THERMIQUE (intérieur)

PHOTOGRAPHIE N. 3

Intégration de l'actographie dans la chambre d'exposition

TOXICOLOGICAL INVESTIGATIONS OF FLIGHT ACCIDENTS: FINDINGS AND METHODS

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SUMMARY

After accidents with fume in the cockpit a characteristic profile of pyrolysis products is gaschromatographically often detectable in the blood. This profile we have to distinguish from an inhalation of fuel or from a fasting blood. The sensitivity was improved. If carbonyl compounds are supposed in the biological materials, we identify them by the reaction with semicarbazide in the head space bottles of the gaschromatograph. From about 5% CO-Hb, we determine photometrically the cyanide level.
After a fatal crash over the sea bromide-concentrations were found in the examination materials, which exceeded clearly the physiological area. All previous results with essential longer immersion-times in sea-water told against a contingent uptake of bromide from the sea. Experiments with animal and human lungs demonstrated, that we have to calculate with such an enrichment in biological materials yet. With this knowledge, a second pilot in an analogous case could be cleared from the suspicion of having abused bromine containing sedatives, too.
In estimating the blood alcohol level of one material from a corpse, we ascertained gaschromatographically distinct higher values than with the enzymatic method. Further examinations showed that, caused by bacterial putrefaction, an alcohol formation occured during the sample preparation. Any alcohol concentrations in the elder literature have to be regarded under a new aspect after that.
In some investigations of dead pilots we identified hypnotics. In one case it succeeded to determine the time of intake with the more unspecific thin-layer chromatography instead of mass spectrometry. According to that, the extraction procedures became modified. The different used extraction methods for the single drug categories will be compared.

INTRODUCTION

The medical investigations of military or civil flight accidents are not complete without chemical-toxicological analyses as a rule. Here examinations will be presented, which caused variations in the scheme of the chemical laboratory. The procedures therefore resulting will be compared with the traditional ones.

The so-called expression "smoke in the cockpit" may refer to a wide variety of processes - the fumes may originate from an overloaded battery or may consist of water vapor from the cockpit heating system. However, it could also be oil vapor or smoke generated by a burning cable. The two latter defects manifest themselves by a characteristic profile in the gas chromatogram.

For analyses of this kind, we use columns of 2 m x 1/4 inch with 15% Carbowax 1500 on Chromosorb W-NAW. The temperature of the oven ist 85° C, that of the injector is 120° C and that of the FID is 150° C. 42 ml of N_2/min are used as carrier gas.

2 ml of cooled blood or fluid pressed from tissue with 1 g of K_2CO_3 or 2 ml of urine with 2 g of K_2CO_3 are filled into cooled head space flasks with a capacity of 20 ml each to serve as samples. However, changes in carbonyl compounds caused by the alkaline medium must be reckoned with. 1 or 0.5 ml of gas phase of the sample which is kept at a constant temperature of 60° C are injected.
A gas chromatogram which would characterize the above mentioned defects must at least contain 3 pronounced peaks or 4 peaks of different heights in front of acetaldehyde, i.e. in front of n-hexane. They denote low-molecular hydrocarbons which have developed as a result of pyrolysis of organic material. For better perceptibility Fig. 1 shows a spread chromatogram, the technique will be mentioned later.

A chromatogram of this kind must be distinguished from that of somebody who has absorbed kerosine (Fig. 2) or who has not had breakfast yet (Fig. 3) or from a chromatogram which is impaired by impurities in the air of the laboratory (Fig. 4) or by transportation in vacuum syringes made of plastics.

Using the same injection, we determine from a crew member's blood whether he was under the influence of alcohol, or from his blood or urine whether certain diabetic conditions were present. Putrefaction which could also lead to false results in the testing of material is also recognized using this method. However, the mutual influence the different alcohols have on the respective retention times must also be noted (Tab. 1).

By means of a second injection taken from the same sample flask, the range of components with a higher boiling point is examined at a column temperature of 140° C.

If a chromatogram seems to contain several substances with almost identical retention times, another sample is bottled, which, however, is injected at an oven temperature of 70° C with 40 ml of N_2/min, while the paper speed is slowed down by a factor of 10. These conditions are generally sufficient to achieve a differentiation between similar peaks.

When the message "smoke in the cockpit" is received, two more head space flasks are immediately filled with 2 ml each of the material to be tested. However, the salt that is added consists of sodium acetate and in addition one flask contains semicarbazide in an amount that fits on the tip of a spatula. If in the first chromatogram there are peaks which may belong to extraordinary aldehydes or ketones, flasks 2 and 3 are used in order to identify components of this kind. The increase in the pressure of the vapor which is caused by sodium acetate is of course smaller than the increase brought about by potassium carbonate. Using this method, we for example identified formaldehyde several times; we of course always identified acetone and acetaldehyde but rarely found methylethylketone. However, we very often noticed an increase in a C_5-ketone, probably diethylketone, which has biological reasons. Unfortunately we have no literature at our disposal which would provide information on the way this compound develops.

By means of a parallel analysis carbon-monoxide-hemoglobin is identified photometrically applying a "9 wave lengths method". If as a result of "smoke in the cockpit", the carbon monoxide content exceeds certain given limits, the cyanide content is determined. We presently use the photometric method of Pranitis and Stolman[1].
A level of 3 % of CO-hemoglobin found in a non-smoker who, after discovering the smoke, switched to 100% oxygen, definitely exceeds this limit. In the case of a smoker, the type of aircraft, the flying time, the time of oxygen inhalation and the time that has elapsed since the incident occured must be taken into account. If the quantity of the cyanide found exceeds 0,4 µg/ml, investigations will be directed if a fire or a smoldering fire had happened which might have affected polyamide-, poly-urethane- or polyimide-parts.

If the determined values point to an intoxication by carbon monoxide or to a combined intoxication, the flight surgeon must be informed immediately as it may become necessary to ground the person concerned.

After a fatal flight accident on sea, we conducted an X-ray fluorescence analysis and found the following bromide concentrations in the materials tested (Tab. 2):

We accept values up to about 1 mg % as normal.

The corpse was only moderately destroyed; the immersiontime in the sea amounted to 4 hours approximately. The toxicological examinations did not indicate the presence of drugs or any metabolites resulting from them.

The analysis was carried out under the following conditions (Tab. 3):

In all earlier analyses following a fatal crash on sea, the bromide concentrations found had been normal. Here, only those cases are listed in which the corpses had been exposed to sea-water for a relatively long period of time and partly had suffered severe damage (Tab. 4).

Later analyses yielded analogous results and are, thus, also shown here (Tab. 4a).

This meant that only tests could provide information on whether absorption of bromide from sea-water by parts of bodies is possible. For this purpose, the fresh lungs of pigs and later human lungs were placed into sea-water.

The table shows that bromide was absorbed in all cases (Tab. 5).

Parallel to that the amount of chloride increases, as is to be expected. (Tab. 6) This means that we must reckon with the possibility that corpses may absorb quantities of bromide approximately up to the content present in the sea-water, no matter to what extent they have been destroyed and largely irrespective of the time they have been exposed to the water[2].

These findings enabled us to invalidate the suspicion that the victim of another crash had taken drugs containing bromine (Tab. 7). This dead too, was only destroyed moderately and had been exposed to the water for approximately 4 hours. Also in this case, the toxicological analyses did not provide any indications of the presence of drugs or resulting metabolites in the material tested.

In the case of another dead, who had been recovered from the sea after 7 days, we were surprised by the results of the blood alcohol determination. In spite of repeating the analysis we found 50% and 175% more ethanol when employing the gas chromatographic method as compared to the enzymatic method (Tab. 8). We found an explanation for these impossible results when we detected that less alcohol was indicated after the period of thermostatisation of the head space flasks had been halved, but even higher ethanol concentrations were indicated after this period had been doubled. In other words: Ethanol had developed in the sample flasks during the thermostatisation process. A microbiological analysis showed that the material to be tested was contaminated by various genera of enteric Bacteriaceae. In contrast to the lungs, the spleen did not smell of putrefaction.

These observations might be an explanation for several peculiarities in elder alcohol determinations in which the volatile substances had been distilled off under neutral conditions and at a reduced pressure. Decay processes of this kind are in principle also conceivable after pieces of tissue have been weighed into head space flasks.

In the cases of several analyses after flight accidents we detected hypnotics of the benzodiazepine family in the biological material. In spite of the fact that non-chlorinated solvents had been used for the extractions, the metabolites, artefacts and parts of unchanged drug appeared in all 4 extracts, i.e. in the acid extract and in the following alkaline one. After the following hydrolysis, parts of these substances again appeared in the acid extract and parts of them in the subsequent alkaline extract. Detection sensitivity may be considerably impaired as a result of this fact. Since we made these observations, we have always exposed 2 to 3 ml of urine or blood to direct hydrolysis; we then only produce an alkaline extract and apply the entire residue to a thin-layer foil which we use for identification by means of the Bratton-Marshall reagent[3] or another suitable reagent. In one case we even succeeded in identifying the metabolite hydroxyethylflurazepam and its fission product which are important to determine the time of ingestion, whereas the mass spectrometer failed in spite of selected ion monitoring as far as the standard extracts were concerned.

For the extraction of pharmaceuticals and drugs of abuse we mostly use XAD-2 columns. If only a screening from a urine is required, most frequently only an alkaline elution is conducted first. As a result of this process, the important barbiturates also get into the extract in the familiar way. However, we use as a rule dichloromethane with 5% of i-propanol and subsequently ethylacetate for elution. It is to be noted that the solvents are not mixed.

If special acid compounds are to be identified from blood, the blood is first precipitated with an equal volume of acetonitrile. After centrifugation, the supernatant is put on a XAD-2 column for acid extraction.

Fortunately, we only receive few requests for the determination of drugs of abuse and thus we can afford to concentrate large quantities of urine by means of freeze drying, slightly acid urine, self-evident. In the case of hashish, the whole process must be carried out in darkness, of course, and the individual analysis steps should be carried out in quick succession, losing as little time in between as possible. Under these conditions the detection of cannabinol and cannabidiol with their long half-live times by means of thin-layer chromatography is quite sufficient.

We identify cocaine using the mass spectrometer, methylating its main metabolite with the help of trimethylaniliniumhydroxide according to the flash heater method.

We use the same derivatisation method in order to detect biochemical changes. After the urine has been saturated with sodium chloride, we use ether for acid extraction, followed by ethylacetate. As a result, the scope of substances that can be determined by mass selective detection ranges from hydroxy acids to neutral substances.
In this respect we expect a valuable help by the new atomemission detector, especially in identifying unknown metabolites.

Let me state finally that our future work will include in a forced manner tasks of the occupational medicine that occur in the area of aviation.

Also a great problem will give the detection of highly affective modern drugs, that means used in doses of approximately 0,1 mg. We have to develop more sensitive extraction methods for this purpose and last not least, we need the most sensitive analytical equipment.

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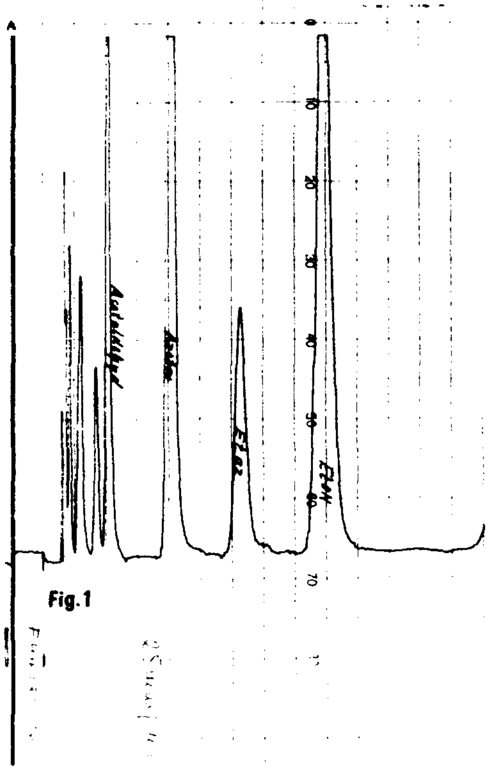

Fig.1

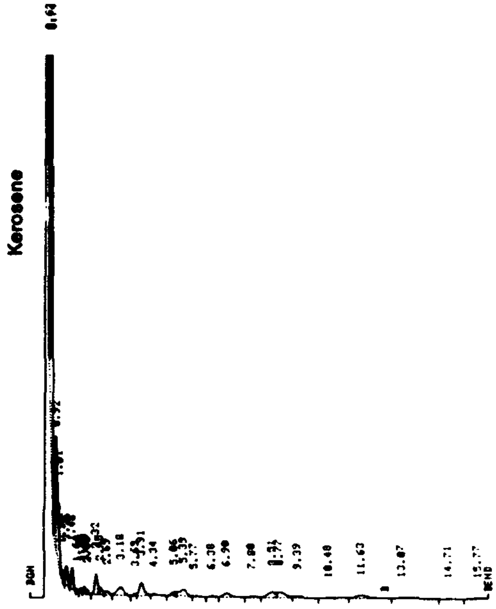

Fig.2

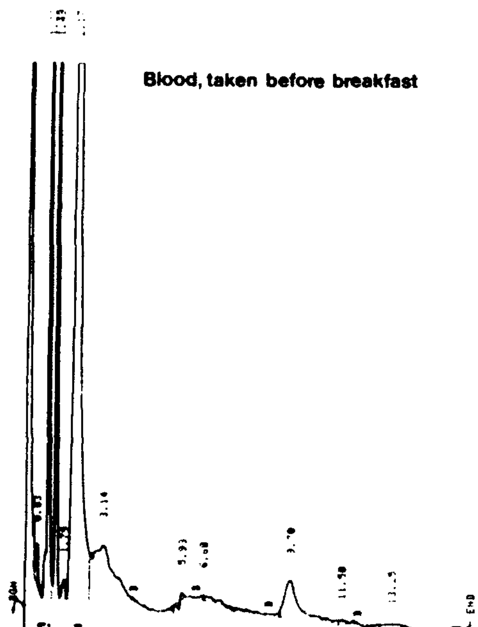

Fig.3

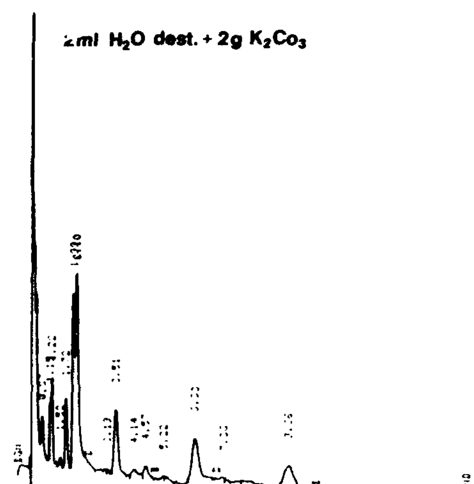

Fig.4

Tab. 1 **Retention times**

	single substances	miscellanous
Ethanol	2,26	2,15
Butanol-2	3,46	3,28
n-Propanol	3,85	3,58
i-Butanol	5,05	4,68
n-Butanol	7,00	6,48

Tab. 2 **Case 8 M, bromide content**

Fluid from pressed lung	1,57 mg%
Stomach content	1,95 mg%

Tab. 3 **X-Ray Fluorescence Conditions**

Spectrometer PW 1410 (Philips)
Molybdenum tube
60 kV
25 mA
LiF-crystal
scintillation counter
2 Θ angle 29,9 $K_{\alpha 1}$ and 30.0 $K_{\alpha 2}$
collimator fine
5 ml fluid cuvets

Tab. 4

Former cases with normal bromide levels

immersion time in sea	state of the corpse	analyzed material fluid pressed from
22 h North sea flats	large destruction	muscle
66 h Ysselsea	large destruction	lung
few h Baltic sea	large destruction	lung
7 days Baltic sea	no destruction	spleen

Tab. 4a

Later cases with normal bromide levels

immersion time in sea	state of the corpse	analyzed material
104 h North sea	large destruction	fluid pressed from
" " "	small destruction	muscle
19,5 h Baltic sea	no destruction	thoracic blood
" " "	no destruction	thoracic blood

Tab. 5

Experiments in account of a bromide admission

fluid pressed from pig lung	0,00	mg %	bromine
North sea water	5,00	"	"
fluid pressed from pig lung			
24 h deposited in sea water	2,80	"	"
48 h deposited in sea water	3,15	"	"
synthetic seawater	4,90	"	"
fluid pressed from human lung	0,38	"	"
fluid pressed from human lung			
3 h deposited in sea water	3,30	"	" (– 0,38 mg %)
6 h deposited in sea water	4,60	"	" (– " ")
24 h deposited in sea water	4,60	"	" (– " ")

Tab. 6

Chloride admission from sea water

fluid pressed from human lung	0,35 %	Chloride
Lung (value from literature)	0,25 %	Chloride
conversioned according to water content	0,31 %	Chloride
fluid pressed from human lung, deposited 3 h in sea water	1,24 % (-0,35 %	Chloride ")
fluid pressed from lung of case 3 N	0,70 %	Chloride

Tab. 7

Case 3 N, bromide content

fluid pressed from	
lung	2,24 mg % bromide
muscle	2,00 mg % bromide
liver	2,56 mg % bromide

Tab. 8

Case O 6, alcohol formation

fluid pressed from	gaschromatographic	enzymatic
lung	0,44 ‰	0,29 ‰
spleen	0,94 ‰	0,34 ‰

27 YEARS ARMED FORCES AEROSPACE PATHOLOGY AND TOXICOLOGY IN THE FEDERAL REPUBLIC OF GERMANY: DEVELOPMENT, CURRENT STATUS, TRENDS AND CHALLENGES

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Summary

The west German armed forces Aerospace Pathology and Toxicology was founded in April 1964 as a division of the German Airforce Institute of Aerospace Medicine. Prof. S. Krefft was assigned the development of this division in a time of increasing accident rates due to the so-called "F-104 G Starfighter crisis". Krefft developed the concept of a mobile, airborne investigation and autopsy team with centralized laboratories for identification, histopathology and toxicology at Fürstenfeldbruck AFB, near Munich. Though the doctors of the autopsy team normally are adressed as pathologists, they are in fact forensic pathologists, thereby meeting the requirements of german law.
Trends in accidents and incidents are evaluated and discussed with respect to future developments. New methods and techniques are presented such as DNA-based identification.

Introduction and History

By founding the Institute of Aviation Medicine in 1959, the German Air Force early responded to special aeromedical questions raised by the increased employment of jet aircraft.

This institute was established at the Fürstenfeldbruck military airfield and, with its departments, has ever since contributed under various aspects to enhance flying safety and supported the flying units of all three services.

Department V - Aerospace Pathology and Toxicology - was established in April 1964 at a time when the number of aircraft accidents strongly increased owing to the so-called "F-104 Starfighter crisis".
The reasons behind the foundation of the department were the expectation and requirement of the military commands and units to clarify growingly urgent medical aspects in flying safety. The investigation of aircraft accidents caused by the "human factor" had become more and more important. Professor Krefft, the former head of the Institute for Forensic Medicine of the University of Leipzig, was tasked to build up and manage the department.

Tasks and Requirements

What have ever since been the objectives of Aviation accident medicine?
In our department aircraft accidents and incidents are evaluated and analysed in order to draw conclusions how accidents may be prevented and cockpit safety improved in cooperation with aircraft engineers and developers.
As an example it may mention the improvement of the sheath of the pilot knife. It had frequently happened that the extreme acceleration force typically occurring in aircraft accidents and incidents pressed the knife through the sheath what caused partly severe injuries at the pilot's lower leg or foot. On the basis of this findings, the material of the sheath was reinforced and the pilots were advised to wear their knife in a different way. Since that time such type of injuries had not been observed any more.

Complying with the legal provisions the department is recognized as an expert agency by civil authorities such as the public prosecutor and therefore has the same legal status as the institutes for forensic medicine.

On order of the General of Flying Safety the department takes up the investigation of all military flight operation disturbances provided that persons were injured or killed or medical aspects of flying safety were concerned.

Thanks to the central function of the department an organization could be built up in the course of time with sufficient staff and equipment to support also the Federal Aviation Office in Braunschweig in case of civil aircraft accidents. Moreover, members of the department also support the victim identification section of the Federal Office for Criminal Investigation in case of disaster. To mention in this context is the participation in the identification of 155 victims killed in an aircraft crash on Teneriffa. Only recently the department received a mobile X-ray equipment for this purpose. In the scope of the required identification measures, skeleton and teeth of the victims are X-rayed; the plates are then digitized in order to display them on screen and save them on disks for later comparing examinations.

Apart from numerous employments in the area of the Federal Republik of Germany, the department had also investigated aircraft accidents in various NATO countries. The largest military operation in a foreign country took place in 1975 after the Transall crash on the island of Crete in which 42 soldiers were killed. All of them could be identified.

Since its foundation, the department has been employed in 260 accidents claiming a total of 652 casualties. Until the early

70ies, the majority of aircraft accidents involved jet aircraft, in particular starfighters; another climax was reached in the late 70ies and the early 80ies. Helicopter crashes ranged from 0 to 5 per year. Since 1971 there were never more, than two accidents to notify.
With Propeller Aircraft happened also 0 to 5 accidents per year, the majority of them with Piaggio and light propeller aircraft. From 1978 till 1989 there was no accident with a propeller aircraft.

In the last years the cooperation with the Federal Aviation Office in the investigation of civil accidents was intensified, certainly also due to the decrease in military accidents. The investigation team worked in 1990 and 1991 on 26 accidents with a total of 50 victims. In only six accidents military aircraft were involved.

The basis for the development of expert opinions is provided by the scientific methods of the forensic medicine and associated disciplines such as traumatology, traffic medicine, toxicology, serology and trace analysis.

Organisation and Structure of the Department

The department, headed by a specialist in forensic medicine, is organized in various divisions.
Professional investigations of aircraft accidents are ensured by a mobile investigation team on permanent stand-by. Today it is usually comprised of two medical practitioners, one of them a specialist in forensic medicine, a photographer and two autopsy assistants. Immediately after being notified of a deadly accident, the team moves as fast as possible by aircraft, helicopter or car to the scene of the accident. At the site, the aeromedical examinations are conducted in close cooperation with the responsible flying safety officers, the flight surgeon, the public prosecutor, the police and representatives of the Federal Aviation Office.

Special attention is given to the crash point and fragments of the aircraft as well as to the position and posture of the corpses which alone frequently reveal details of the accident event. First identification measures are taken.

On request of the public prosecutor the post-mortem examination is done with the primary objectives of:

- final identification
- establishing the cause of death
- documentation of injuries on the body surface, skeleton and inner organs.

Accident-specific injuries such as seat belt marks and stick injuries are of special interest. The palms including the joints and the soles of the feet are prepared. Extensive biological material needed for later histological, serological and toxicological processing and for the evaluation of traces is preserved. All findings of recovery and autopsy are documented by tape recorder. Totals and close-ups are shot of site and autopsy.

Histology

The specialist division for histology, histochemistry and trace analysis features all major routine methods. In 1979, the spectrum of histological examination methods was enlarged by the procurement of an electron microscope which provided the possibility to document histomorphological tissue changes to a high degree of differentiation. The electron microscope is also used for purpose-oriented research.

In previous years some 2500 microscopic sections were cut and evaluated, where as in the last few years the annual number of histological cover-glass preparations went up to about 5000.

After deadly aircraft accidents tissue samples are taken from all found organs for histological analysis and assessment also in order to diagnose possible previous diseases which may have affected the pilot's fitness to fly.
For example, it has been found out that a pilot had suffered from a syringomyelia, a fact that was not known by then. Moreover, the histological analysis may answer questions about the vitality in case of injuries caused by external violence.

The classical methods of serology which are primarily applied to identify corpses and to detect blood stains next year will be supplemented by the DNA analysis. Methods like Ouchterlony's only allow to differentiate between human and animal tissue. The absorption-elution method is used to determine whether blood traces belong to type A, B or AB. Last year the department investigated a Tornado accident in the Netherlands, causing two victims. Since the aircraft crashed into the North Sea only very little organic material without any characteristics usable for classical identification methods was found. In such a case, a doubtless identification is only possible with the aid of the lately developed DNA fingerprinting method which allows the determination even of very small parts of the corps. The DNA is removed from the existing tissue and treated with restriction enzymes. The gendetermined distribution of the outcoming length of the fragments can then be detected with so-called DNA probes. Following this analysis the DNA fragments can be compared, and checked for correspondence, with the blood of the victim's next of kin.

The specialist division for identification, preparation and aircraft accident reconstruction makes, as directed by a surgeon, specific preparations and submits them to a possible further medical examination such as recovered teeth or parts of upper and lower jaw which are excellently suitable for identification.

This specialist division keeps a traumatology documentation and evaluation which is intended to explain the mechanisms leading to typical injury patterns directly resulting from the course of events during an accident.

<u>Toxicology</u>
Aerotoxicology has gained in importance in the investigation of aircraft accidents. This specialist division conducts analyses after aircraft accidents and incidents and delivers toxicological expert opinions on request of flight surgeons, Bundeswehr hospitals and other Bundeswehr agencies. The main tasks of this division are the development and employment of special aerotoxicological examination methods to detect exposures to smolder gas, combustion gas, fuel, hydraulic liquid, defrosting agents and other toxicological risk factors which may result in a temporary or permanent impairment of the fitness to fly or which may give indications of the cause of an accident.
It was possible to lower very much the concentration limits to detect volatile substances. After only one or two respirations of contaminated air it can distinguish in blood samples between hydraulic liquid, cable burning or other toxic gases.
Non-negligible risk factors are now as before the pilots' consumption of alcoholic beverages and the uncontrolled taking of medicaments. Latent induced or endogenic metabolic disturbances and the resulting slips represent other risks for flying operations and safety.

Various body fluids like blood, urine and compressed lung and muscle fluid are separately processed and analyzed using different problem-oriented methods.
Blood alcohol levels are measured with enzymic and gas chromatographic methods. The recent new legal provisions concerning the blood alcohol analysis claim for a higher standard of quality control. This means the participation in ring experiments which is required for the legally accepted routine examination of blood alcohol concentrations.
Carbon monoxide contents are presently determined using ultra-violet photometric methods, while hydrocarbons are analyzed with the aid of gas chromatography. Drugs, narcotics and other medicaments are analyzed using thin layer chromatography, high-pressure liquid chromatography and gas chromatography in combination with mass spectrometry or a mass sensitive detector.
The mass spectrometric methods permit the detection of substances even in the magnitude of as low as picogramms per milliliter.

The number of toxicological examinations went up in the last few years, among others, due to drug screenings.
Because of the growi[illegible] ecological awareness, number and versatility of examinations in the field of occupational medicine have also increased.

In 1991 in total 490 toxicological analyses were conducted.
So the biological material of 27 casualties of fatal aircraft accidents was examined with 81 routine examinations like blood alcohol, carbon monoxide and pharmaceutics and with 135 subsequent analyses. 91 examinations were required in non-fatal aircraft accidents and incidents.
In the last year, the other toxicological examinations included 124 scientific tests and, for the first time, 51 drug screenings.

<u>Final Notes</u>
The combination of military and legal requirements demands absolutely exact analysis results for the different substances which are irrefutable before the court. Analysis methods are therefore permanently being developed and improved. The existing gas chromatography with mass spectrometry and the high pressure liquid chromatography equipment will soon be completed by specific detectors like Ion Trap to achieve still more precise analysis results. The atom absorption spectrometry will allow the detection in particular of metals and heavy metals.

Besides the specialist divisions, the department has a comprehensive record office storing - partly with the aid of a computer - all collected and evaluated data of accidents and incidents. Moreover, exists an extensive exhibition with organ preparations, dry exhibits, diagrams and picture boards, trajectory and aircraft models.

In autumn of this year, the department will move into a new building and there be linked to a network to get access to the institute's computer information system. It will then be possible to evaluate data of aircraft accidents, toxicological measurements and traumatological and histological examinations with still a higher exactness.

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SIGNIFICANCE OF HISTOLOGICAL POSTMORTEM FINDINGS IN PILOTS KILLED IN MILITARY AND CIVIL AIRCRAFT ACCIDENTS IN GERMANY (WEST): A 25-YEAR-REVIEW

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Summary

The Division of Aerospace Pathology and Toxicology ("Flugunfallmedizin") at the German Air Force Aerospace Medical Institute was founded in 1964 by Col.Prof. Krefft and is since then located at Fürstenfeldbruck AFB near Munich. The Division is engaged in the medical and medico-legal part of all fatal accident -, most non fatal accident - and incident investigations concerning German military aircraft (Airforce, Navy and Army). The Division performs also some civilian medical accident investigations for the Federal Aviation Administration ("FUS, Flugunfall Untersuchungsstelle beim Luftfahrt Bundesamt").
The autopsy files of the period 1 January 1965 up to 31 December 1990 were reviewed. In 231 civilian and military crashes a total of 455 autopsies was performed, resulting in 385 valid autopsy reports of killed pilots including a histopathological examination.
Histopathological findings were coded and stored in a data base of an IBM compatible computer. In those cases with positive histopathological findings in the files the tissue was reexamined.
36 cases showed severe histopathological alterations. 21 of these might be considered to have reduced physical and / or mental performance and thus have affected the capability of flight safety.
A selection of ten cases is used to discuss problems of accident causality in case of positive histopathological findings. The value and validity of findings especially in those cases of a high degree of tissue destruction is demonstrated.
In aircraft accident investigations autopsy and histopathological examination must - on the basis of nearly 5% positive histopathological findings - be regarded as mandantory.

Introduction

The casualties of military and civil aircraft accidents are usually subject to a post-mortem examination on order of the public prosecutor. This investigating authority is primarily interested in the cause of death and in the answer to the question whether or not there was a causality between a false act of a third party and the death of the persons concerned. Minor importance for the public prosecutor have the questions about the sequence of events or the cause leading to the accident to establish accident prevention measures as a consequence of the assessment of all circumstances.

In case of accidents of military aircraft the competent investigation committee of the Director of Flying Safety, Federal Armed Forces, is interested in the examination of the accident's cause and deductable measures to prevent similar accidents; the flight accident investigation agency of the Federal Aviation Office does the same in case of civil aviation accidents.
The public prosecutor's securing of evidence requires in addition to an autopsy also histological, toxicological and other examinations; the reason behind is that any incompleteness of medical findings would be exploited by the counsels of the defense to put forward irrefutable assertions which would overstress in trial the legal principle of "in dubio pro reo" (in a doubtful case, it shall be decided in favor of the accused). Still more detailed examinations, especially those under the microscope, are particularly useful to establish statements on possible previous diseases and their influence on the sequence of events leading to the accident under the aspect of the human factor as cause of an accident. Moreover, microscopic examinations allow to separate vital from post-mortal findings, to establish chronological relations in the course of the accident and the origin of different findings and, if required, to recommend necessary modifications in the design of flight equipment or the aircraft itself.

In general, the complex investigation of an accident requires statements about microscopic changes of the tissue of inner organs in supplement to post-mortem findings.

The following cases will demonstrate how organic changes only detectable by histomorphological methods permitted conclusions as to the aircraft accident events and had to be accepted as links in the chain of causality.

Material and methodology

In the scope of aircraft accident investigations of the last 25 years, the court-ordered post-mortem examinations of military and civil pilots revealed pathological organ samples indicating diseases which could have impaired the fitness to fly at the time of the accident. 230

evaluated aircraft accidents between 1964 and 1990, 10 percent of them involving civil aircraft, required 455 autopsies for analysis, 385 of which were post-mortem examinations of the responsible pilots. The files contained 36 cases (about 10 percent, one fourth of which were civil pilots) with manifest histopathological findings. 21 cases showed changes which would have principally been suitable to explain a degradation of the fitness to fly at the time of the accident, among them two verrucous, non-bacterial endocarditides, two cases with constrictive juvenile coronary arteriosclerosis, one chronic gastro-enteritis, one disseminated vasculitis, one miliary epithelial cell granulomatosis, one myocarditis and one mycosis of the lung.

Case 1:

In 1970, a 26-year-old pilot crashed with his F-104 on the Bergen-Hohne major training area. The pilot had an experience of 674 flying hours, 286 of them on the aircraft type involved in the accident.

No previous fitness to fly tests had revealed any peculiarities. Looking back, his superiors had only noticed that the pilot's shooting results had become worse from year to year.
The histological examination of the spinal cord revealed a syringomyelia.

In this case two cavitations were observed at the right and left side of the central canal in the cervical part of the medulla including a displacement of the rear and/ or front chamber. These cavitations covered the entire cervical part towards the upper sections of the thoracic cord and the ventricornus. Such changes may cause dissociated paralgiae with a diminution of pain and temperature sensitivity; they may also cause secondary muscular atrophies - located in the lower cervical part - initially at the small muscles of the hand.

Owing to the slow development of such symptoms the pilot and the people around him may not have noticed the associated disturbed nervous functions.

Case 2:

In 1970, an F-4E comes into an instable pitch position after a pullout maneuver ending up in a too steep climbing angle. The two crew members were ejected at an altitude of 2000 ft. whereby the responsible 38-year-old pilot was deadly injured. The pilot had an experience of 3526 flying hours, 722 of them on the aircraft type involved in the accident.
Already twelve years before this fatal accident an unspecific border line alteration in the EEG of the pilot was measured in a fitness to fly test which indicated a lack of cerebral vasostability with symptoms of a significant autonomic instability; these findings were more or less distinctly confirmed in other EEG measurements in the following eleven years. Nine months prior to the accident, an unsteadiness in one-leg-standing and tightrope walking was stated in a fitness test for military flying duties. As a result of these findings the pilot was allowed - one year before the accident - to fly only with a co-pilot and only on aircraft/helicopters with dual flight control and a co-pilot with type rating. After a post-examination six months before the accident, the restriction "flying with co-pilot only" was removed.
The histological examinations revealed a moderately developed coronary arteriosclerosis in the myocardial tissue which had already produced a perivascular tylosis at several spots.

Indicators for a brown atrophy of the myocardial fibres were also detected. In addition, circumscribed angiomatoses in the brain were found both in the subependymal area of the occipital cornu of the left ventricle and in the plexus choroideus. The walls of the dilated vessels seemed largely hyalinized and partly showed stripy, loose round cell infiltrates. Amyloid and hemosiderin test negative! The neuropile of the left occipital cornu in the area of these vascular changes did not show any detectable morphological damage.
In other regions of the brain, however, diffused and grouped nerve cell deficiency symptoms were observed in all cortical layers and in brain stem nuclei. An increased pigment atrophy of the nucleus dentatus and a partial disturbed function of the Purkinje cells were significant in the cerebellum. The histological findings in the brain gained by microscopic examinations may be the morphological correlate for the observed EEG changes, for the unsteadiness in one-leg-standing and tightrope walking, caused by recurred states of hypoxia or by circulatory disturbances.

Case 3:

After touching the ground and again shortly bumping off, an F-104G crashed on the firing range of Helchteren in Belgium. The 36-year-old pilot was hurled out of the aircraft and killed.

The pilot had an experience of 3543 flying hours, 1942 of them on the type involved in the accident. No peculiarites had been observed in the fitness to fly tests of the years prior to the accident. In previous years increased blood pressure values had been measured (maximum 170 mm Mercury) which, however, went back to normal again. Nine years before the accident the ECG showed spurious repolarization disturbances after work which, however, did not depart from the norm.

The post-mortem examination revealed, in correspondence with the macroscopic findings, a significant general arteriosclerosis of the body's main artery as well as an arteriosclerotic constriction of the coronary vessels of up to 75 percent of the lumen. Accordingly, there were a disseminated tylosis and a circumscribed interstitial fibrosis also in the myocardial tissue.
Under extreme physical strains, such sclerotic coronary vessels may cause - owing to the sudden relative coronarism - an acute insufficient blood supply of the

heart, reducing its pumping performance and, consequently, causing an insufficient oxygen supply of the brain. These facts may give an explanation for delayed reactions and mental coordination disturbances.

Case 4:
In 1969, a 36-year-old pilot lost control over his C-47 when he tried to land on the runway in Husum. The aircraft went up again from the runway and crashed afterwards almost vertically with the cockpit into the ground. Three of the passengers were immediately killed, the fourth died one day later.

The responsible pilot had an experience of 3073 flying hours, 839 of them on the type involved in the accident. No peculiarites had been observed in the previous fitness to fly test. Four months prior to the accident, the pilot had stayed in a health resort because of a circulatory lability and hypertension. The post-mortem examination showed pericardial adhesions to the cardiac wall which could be confirmed to be chronic-inflammatory changes of the serous membranes of the heart without fresh cell reactions. In addition, there were maculated old cicatrices in the myocardial tissue while the coronary showed no peculiarities.
A chronic bronchitis and a structure fibrosis were apparent in the lung tissue. These lung changes - visible only under the microscope - had caused a right ventricular hypertrophy (0.6 cm ventricular wall thickness at the pulmonary outlet) which had already been stated to be pathological in the macroscopic post-mortem examination. In addition, irritable vessel reactions in heart, liver and spleen corroborated the existence of an acute infect prior to death.

The organic changes detectable in both macroscopic and microscopic examinations indicate a degradation of the pilot's stress resistance at the time of the accident.

Case 5:

In 1990, a 60-year-old pilot crashed with his Cessna 172 onto a meadow near the town of Schoellkrippen. The tests which the pilot had undergone 36 and 12 months before the accident had not shown any peculiarities impairing his fitness to fly. Both examinations were performed without X-raying the thorax, and the last ECG had been made three years ago.

The post-mortem examination revealed in particular an increased weight of the right lung with a hardening of the tissue, watch-glass fingernails and toenails and a distinct, partly almost occluding sclerosis of the coronary vessels .
The additional histological examinations of the lung tissue showed an advanced interstitial pulmonary fibrosis with several honeycomb-like changes of the pulmonary structure. Other regions of the lung tissue showed distinct changes of the pulmonary arterial walls with subtotal arterial occlusions and circumscribed round cell infiltrates. The morphological picture of these changes corresponds to a so-called idiopathic pulmonary fibrosis; however, a line of causality between these findings and a certain accident-triggering cause cannot be established.

Clinic experience knows that such distinct changes of the lung slowly progress over a period of several years. This is proven in the discussed case by the fact that there were watch-glass nails at fingers and toes, a morphological phenomenon which indicates the existence of a chronic pulmonary hypoxia.

Moreover, the additional histological examinations of the myocardial tissue showed a distinct, in part almost occluding sclerosis of the coronary arteries and a connective tissue proliferation in the myocardial tissue. The latter result indicates an already long-lasting hypoxic damage of the myocardial fibres caused by the extreme coronary sclerosis and possibly aggravated by the pulmonary hypoxia.

Under aeromedical aspects, such distinct changes of the lung in connection with a disturbed pulmonary function may have at least contributed, among other factors, to the accident.

Case 6:

A 34-year-old pilot crashed with his F-104G during a night landing approach into a wood near Neuburg on Danube after touching several trees. He did not attempt to eject himself out of the aircraft. The pilot had an experience of 2066 flying hours, 1018 of them on the type involved in the accident.

Details of the pilot's medical history indicated that he had suffered from an acute pulmonary mycosis in the U.S.A. ten years before the fatal accident. In the succeeding years there were repeated inflammations of the nasal mucous membrane. The histological examinations following the autopsy revealed accumulations of epithelial cells, lymphocytes, granulocytes and polyblasts in scarred connective tissue areas. The changes correspond to residual granulomae of the previous mycosis; a typical double-outlined sporont with visible perivascular endospores could be detected in fibrous tissue. Moreover, hyaline pleural swellings were found in some areas.

For obvious reasons, a performance degradation or a diminished fitness to fly may have resulted from constantly recurring allergic or vegetative symptoms or by a reactivation of the mycosis due to a reduced power of resistance.

Case 7:

During a low-level run-in flight, a 30-year-old pilot crashed with his F-104G behind a wooded spot onto the Heuberg major training area. The pilot had an experience of 1172 flying hours, 881 of them on the type involved in the accident. Two years prior to the fatal accident, the pilot fel ill out of perfect health with an epithelial cell granulomatosis (Sarcoid of Boeck) affecting lung and joints. After he was treated with success, the pilot was rated 1b in the subsequent fitness tests for military flying duties without any restrictions imposed.

The histological post-mortem examinations revealed granulomae of a discretely distinct Boeck-sarcoid - being still florid - in both lungs and the associated lymphatic nodes, but the granulomae had a maximum diameter of 1 mm and did therefore not appear on the X-ray.

Though the pilot had not mentioned a degradation of his performance in the past fitness to fly tests, such a degradation and a reduction of his speed of reaction, (possibly by his feeling sick) cannot be doubtlessly excluded according to the pathological-anatomical findings evidencing the still discretely existent Boeck sarcoid.

Case 8:

On a VFR flight in 1990, a C-160 (TRANSALL) touched some trees on an ascending wooded area and shortly afterwards - in a strong lateral attitude - crashed into a timber forest near Lohr upon the Main river. All ten passengers were killed. Neither the previous fitness to fly tests nor the post-mortem examinations of the responsible pilots revealed indications of a reduced ability to fly at the time of the accident.

The additional histological examinations under the microscope, however, obviously showed changes of the hepatic tissue of a 29-year-old crew member who had the function of a cargo officer. The periportal fields appeared enlarged - with regular liver parenchyma architecture - by infiltrates of different cell density (eosinophilic, granulocytes, lymphocytes) as well as by cystic duct proliferation. The distinct centrolobular moderately fatty hepatic cells indicate a disaggregated cytoplasm with a fine-granular or hydropically swollen aspect; the cytoplasm additionally shows dustlike lipofuscin depositions. Destructions of centrolobular hepatocytes were also observed.

This type of changes of the liver, described as toxic hepatosis, are frequently caused by the consumption of certain medicine and do not establish an obligatory manifest disease.

The special chemical-toxicological tests did not produce any indications of the consumption of medicaments inducing such changes.

Case 9:

In 1970, a NORATLAS transport aircraft spinned steep from an altitude of 2000 ft. and crashed onto the Königsdorfer Filz area; the five crew members were killed. The 32-year-old pilot had an experience of 3707 flying hours, 3315 of them on the type involved in the accident. The copilot had been the only survivor of an 11-men-crew after a severe aircraft accident 21 months ago. He showed no peculiarities in the fitness to fly tests in the time after the accident.
The post-mortem histological examinations showed an inflammatory reaction of the liver in the portal fields and in the area of the sinusoides with single cytoclases. In addition to the increased number of mesenchymal cells, inflammatory cells such as lymphocytes, leucocytes and plasma cells were detected.

Considering the symptoms occurring in case of an acute and chronic hepatitis such as weariness, lack of appetite, vegetative symptoms (outbreaks of sweat, general weakness, tendency to collapse, depressions), an impairment of the co-pilot's fitness to fly seems indeed possible.

Case 10:

In 1970, a 33-year-old pilot crashed with his stalled ELSTER-B from low level into a garden within the village of Steyerberg. Both passengers were killed.

The pilot had an experience of 78 flying hours, 36 of them on the type involved in the accident. In fitness-to-fly-tests ten years prior to the accident a hyperthyroidism was diagnosed, showing associated symptoms such as glossy eyes, protrusio bulbi, a moderate vegetative overexcitability, vegetative circulatory lability and a somewhat increased heart rate in the ECG as well as a slightly enlarged thyroid. Because of strong nervous strains, the pilot had been treated with the tranquilizer Valium-5 four weeks prior to the accident; he consumed the tranquilizer until two days before the accident.
In the histological post-mortem examination, the thyroid showed a moderate basedowian goiter with an irregular structure of the differently sized, partly serrated follicles. We found both Sanderson pads in some follicles and concentrations of lymphocytes producing follicles at various places in the intersticial tissue.

These microscopic-anatomical findings established the morphological correlate of the ten-year-old diagnose of the symptoms of a hyperthyroidism with a slightly enlarged thyroid. Because the tranquilizer had last been consumed more than 24 hours before the crash, it can be assumed that this medicine had most likely been excreted at the time of the accident. The symptoms of overexcitability previously suppressed by the tranquilizer should then have been noticeable again.

Conclusions:

The macroscopic findings obtained in the post-mortem examinations of accident casualties mainly serve - apart from establishing criteria for identification - to record the accident traumatology and is insufficient for the clarification of the accident's cause or the sequence of events leading to the accident.
Military pilots undergo extended examinations routinely included for example ultrasonoscopy in the annual tests checking their fitness for military flying duties. Civil pilots undergo these tests every two

years, and it is in the discretion of the examining flight surgeon to use additional diagnostic image-producing methods with each pilot.

In the past 25 years, diagnostic innovations and improvements have resulted in a decrease of the severeness and acuteness of the diseases of the military pilots under examination, whereby the cases with non-detected diseases are mainly limited to the period before the early 70ies. Post-mortem examinations with extended, especially histological additional investigations after aircraft accidents are indispensable in order to increase the quality of aeromedical tests and are an absolute must regarding the presently valid civil system of non-invasive examination methods applied by flight surgeons.

AIRCRAFT ACCIDENT INJURIES IN THE HELLENIC AIR FORCE IN THE LAST 20 YEARS

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SUMMARY

Military flying is a dangerous activity and safety is a major concern. Post accident pathology is an essential tool of determining, the cause of death of the pilot, types of injuries, possible physiological problems that contributed to the accident and finally, possible solutions to improve safety. The aircrew injuries of 151 Class-A Accidents, of the Hellenic Air Force, in the last 20 years. Accidents were divided,according the aircraft type, in three groups: Jet aircraft Accidents, Fixed Wing Props Accidents and Helicopter Accidents. In the Jet Aircraft group, a subdivision was made in three more subgroups: Non ejection attempted, successful ejection and unsuccessful ejection. In all groups the type and location of injuries was recorded, and the results were discussed. An attemption was made to give possible solutions. Injury data bank of airfcraft accidents can be very useful in improving accident investigation techniques and safety and more data must be recorded.

INTRODUCTION

Aircraft accidents are not new occurences. The first reported aircraft fatality occured in 1908 when the Wright Brothers were demonstrating their Wright TYPE-A "Flyer" to the U.S.ARMY. A propeller failure and a crash caused the death of First Lieutenant Selfridge who was aboard as an observer. The autopsy determined the cause of death which was a compound comminuted fracture of the skull.From that autopsy result the investigation board suggested that pilots should wear helmets while flying (4) From this obvious remark, to the investigation of the two COMET accidents in 1954, where the few floating remains of the passengers had signs of rapid decompression and airframe structure failure was suspected (4), post accident pathology proved to be an essential tool for accident investigation and safety improvements. A data bank of aircraft injuries with international cooperation will be of great value to determine aircraft type specific injuries, and possible solutions.

MATERIAL - METHOD

The files of 151 Major or Class-A Accidents of the Hellenic Air Force in the last 20 years were investigated. A Major or Class-A Accident, is one where there is total aircraft damage of aircrew life loss. Data were obtained from the medical files of the 251 Hellenic Air Force General Hospital and the data bank of the Flight Safety Department. Aircraft accidents were subgrouped according the aircraft type. The biggest portion of the accidents was Jet Fighters with 47%, following Jet-Trainers with 15,2%, Jet-Bombers with 8% and Jet-Reconnaissance with 6%. There were 24 Fixed Wing Propeller Accidents (15,8%) and 10 Rotary Wing Accidents (6,62%) (Table 1). Human Factor failure was the main cause of accidents in more than 60% of the Jet-group and in 82% of the Fixed Wing Props and 50% of the Rotary Wing Accidents, which is in accordance with other authors results (2,3,5,6,7) (Table 2). For our investigation purposes the Aircraft Accidents were grouped in 3 major groups according the Aircraft performance and the egress system available: Jet Aircraft group with 17 accidents, Fixed Wing Props with 24 accidents and Rotary Wings with 10 accidents. The type and location of injuries was recorded in each of these groups and there was an attempt to relate specific type of injury to a specific cause. The toxicologic examination was negative in all of the accidents. Also, there was not any case where a previous disease of the pilot was documented to be related to the cause of the accident.

RESULTS

a. JET AIRCRAFT ACCIDENTS

There was a total of 117 Class-A, Jet Aircraft Accidents. A total of 38 pilots, did not attempted ejection and crashed with the aircraft. This leaves little room for injury pattern analysis because of the extremely high impact forces. It is interesting that in the two seat models accidents, 3 copilots initiated ejection sequence little before impacting the ground. This is probably due to the fact that the backseater is more aware of the flying conditions. Question arises as to why they delayed to eject. A part of the answer should be in the highly dominating role of the pilot in command which leaves little room for initiative to the copilot. A total of 10 pilots attempted ejection which was unsuccessful and were fatally injured. 7 of them ejected in very low altitude and were out of seat performance envelope,one ejected in high speed (F5 pilot, Martin Baker seat, 600 knots) and was also out of seat envelope, one was killed due to seat malfunction (T2 pilot, Rockwell, LS-1A seat) and one was killed due to an ergonomics failure. The last case is a good example of how valuable can be post accident injury analysis: After an engine failure, an A-7H pilot ejected over sea. The pilot was found, 15 minutes later, drown with his life support equipment having worked as specified. The autopsy has found that during ejection the pilot felt unconscious after a minor head trauma. The unconscious pilot was unable to release the parachute harness and was carried by the wind. Further investigation showed that the seating height of the pilot was more than 39,7 inches. This is the limit of the 1-G-2 ESCAPAC seat to perform safely.The seat uses canopy brakers, to eject through canopy if the pilot seating height is more than the limit than the pilot head is going to contact first the canopy leaving the pilot unconscious. Now all A-7H pilots are checked for their seating height. The injuries recorded in the above group of unsuccessfully ejected pilots are shown in Figure 1 and are the following: skull fracture with extensive brain damage was present in all cases. In 60% of the cases the helmet was separated either after ejection or after the first impact with the ground. Neck fractures and spinal cord injuries were present in most of the cases as well as massive internal organs injury, long bone fractures and spine fractures were also a common finding. All of those injuries were not survivable due to the high impact forces. In 69 of the 117 accidents the pilots were ejected and the egress system worked successfully. However the pilots received multiple minor injuries for various reasons: (Fig. 2) Low back pain was a common finding and was reported in 8,9% of the cases. Neck sprain was also common in 5,79% of the cases. Poor ejection position was reported as the main cause of the pain. This is also the reason for the T11 - T12 - L1 fractures that were found in 5,9% of the cases. Minor head trauma is also common in 4,3% and can be a life threatening event in ejections over sea. Automatic parachute release is of great value in these cases. Other injuries include femus fracture due to violent landing and shoulder fracture and bruises, due to violent contact with parachute harness, after parachute canopy opening.

B.FIXED WING PROPELLERS ACCIDENTS

Fixed Wing Propeller accidents are almost all survivable. From a total of 24 Class-A accidents, only one accident was fatal causing lifeloss of 3 of the aircrew members. Injury pattern, is shown in Figure 3. The most common injuries were, left femur fractures in 33,3% followed by left arm fractures in 29%, head injuries in 29%, right femur fractures in 12,5% and right tibia fractures in 8,3%. Bruises were very frequently found and were reported mainly in the left side of the body. The left side pattern of the injuries is probably due to the fact that the left side of the pilot body is more exposed than the right which holds the stick. The high incidence of head trauma is because of the fact that most of the aircrew dont wear helmets during the flight and the inertia reel system of the belts seems to fail more often than not.

ROTARY WING ACCIDENTS

Helicopter accidents also have a good survival rate with only two fatal accidents out of 10. In these two accidents a total of 8 passengers and aircrew was killed. Injury pattern is shown in Figure 4. Skull fracture with brain damage was the cause of death in al people killed in the two fatal accidents. In other survivable accidents, skull fracture was present in 30% and head injury in another 30%, and lumbar spine fracture was present in 20%. Bruises were also more often found in the left side of the body. The very high incidence of head trauma is due to the fact that most aircrew members decide to fly without wearing helmets leaving them exposed to head trauma. It seems also that there is room for additional protection systems such as inflatable balloons to protect aircrew from contacting with the panel. Passenger safety should also be under consideration as there is not helmet available for them. (7)

DISCUSSION

H.Wells in his papers of 1915 and 1916 advocated the use of safety helmets and harnesses to avoid injuries sustained during turbulence, aerial combat and accidents. (8) Unfortunately these old statements are proved one more valuable. Fixed Wing Propeller and Helicopter passengers and aircrew not wearing helmet are vulnerable to head trauma which accounds for most of the fatal injuries. In a paper, based on data fran 4500 occupants on U.S. ARMY Helicopter accidents, head injury accounds for almost 31,5% of all fatal injuries and 20% of all major injuries.(1) In our paper head injury accounds for the 29,1% in Fixed Wing Props and in 30% in Helicopters which is in accordance with other authors (1,7). An interesting point is the left side pattern of the body injuries which probably needs attention and more data collection. For this reason a much larger series of accidents is needed. Another point of interest is the big number of non ejection attempted accidents which asks for better understanding and training decision.

CONCLUSION

Post acident injury analysis is a usefull tool for aviation safety. Standardization and report of injuries can be of great value to improve safety systems. The new generation ejection seats are very safe but work must be done to train the pilots to take a fast ejection decision when needed.

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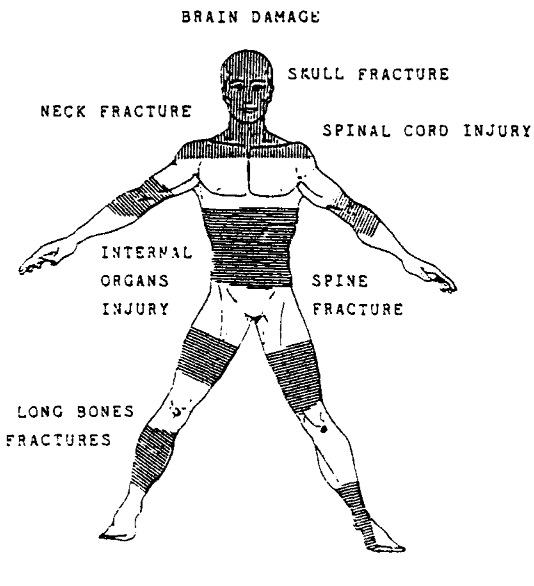
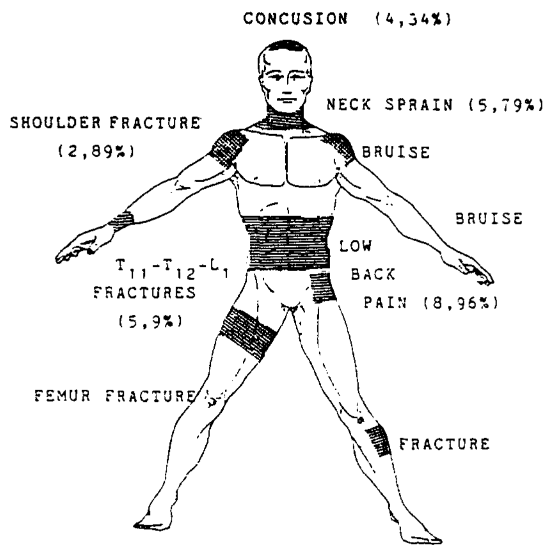
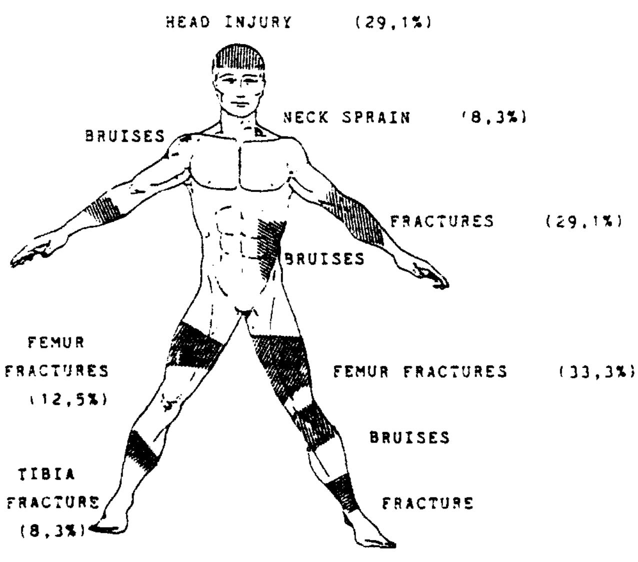


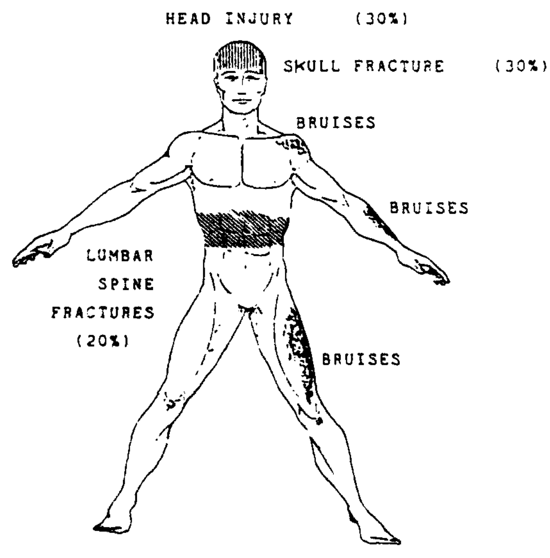
UNSUCCESSFUL EJECTION INJURIES (FATAL)



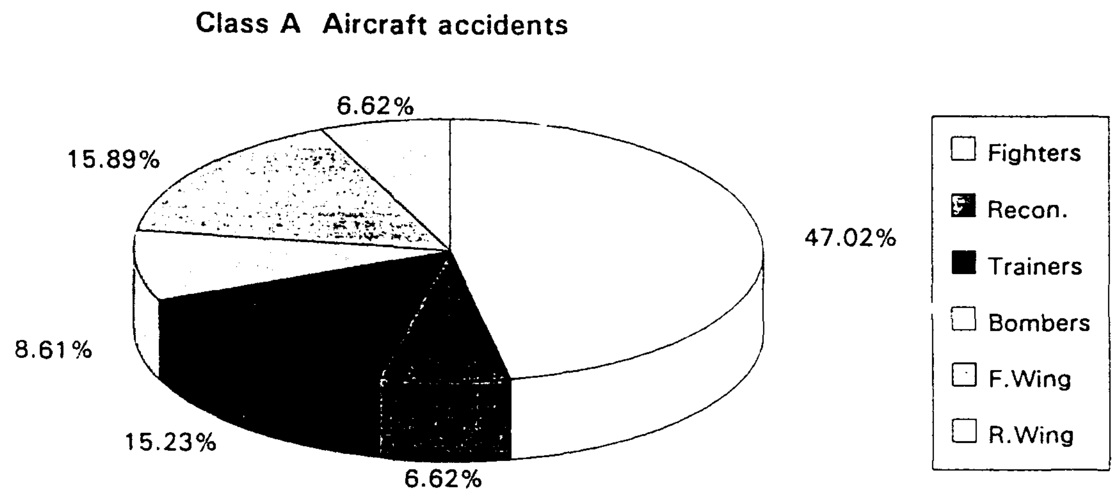
SUCCESSFUL EJECTION INJURIES

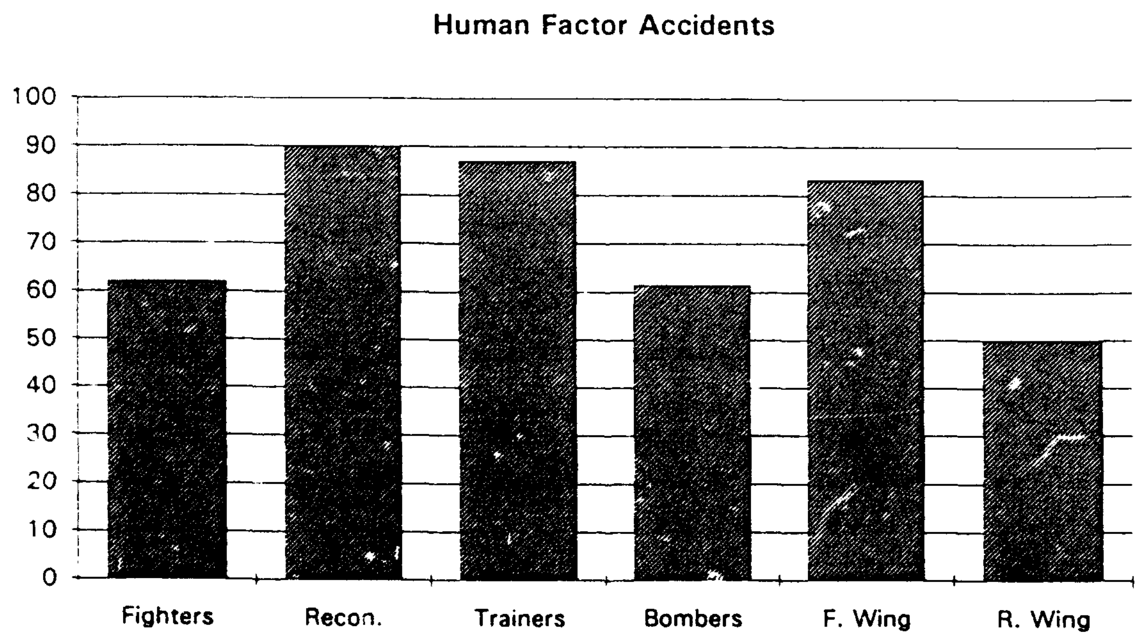


FIXED WING PROP INJURIES (SURVIVABLE)



HELICOPTER ACCIDENT INJURIES (SURVIVABLE)


Class A Aircraft accidents
6.62%
15.89%
47.02%
8.61%
15.23%
6.62%
Fighters
Recon.
Trainers
Bombers
F.Wing
R.Wing


Human Factor Accidents
100
90
80
70
60
50
40
30
20
10
0
Fighters
Recon.
Trainers
Bombers
F. Wing
R. Wing

AN EPIDEMIOLOGICAL STUDY IN SAF'S PILOTS EJECTIONS

by

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SUMMARY
Aircraft escape systems - the ejection seat - have saved a lot of lives, however they often have several secondary problems. First, the physical injuries directly produced by the ejection itself; and secondly, the psychological alterations caused by the fact of suffering from an aircraft accident. This study has been made to get more data on ejections raised in some Spanish Air Force pilots in order to correct the possible mistakes in further ejections. The most remarkable results are: First, the importance of performing the ejection within the safety limits of the seat, and with a very good sitting posture, to minimize possible injuries. Secondly, the necessity for both, ejection seat simulator and parachute training of pilots since most injuries are generated when the pilot has a wrong sitting posture and when he lands on the ground. And finally, the quick incorporation to flying duties as soon as the ejected pilot accomplished his total recovery.

MATERIAL AND METHODS: This study has been made with technical data were obtained from the Spanish Air Force Flight Safety Office. Data about injuries and hospital care was obtained from hospitals and medical officers' reports. Additional information was obtained through an inquiry sent to pilots who were had ejected from their aircraft for last seven years. The inquiry, enclosed a lot of questions arranged by blocks which are in reference to different accident aspects.

About the aircraft: Characteristics and number of ejection seats. Short description of structural or mechanical failure preceding the ejection.

About the pilot: Age, weight, height and number of flying hours. If the aircraft had two ejection seats, did he fly as first or second pilot ? Did the pilot think if he committed any mistake in flight which originated the accident ? What mistake ?

About the accident: Did the pilot have control over the aircraft ? How long was it between human mistake or mechanical failure and ejection ? Could the pilot get ready for the ejection ? Situation at initiation of the ejection: altitude, speed, number of Gs and attitude of the aircraft. Was appropriate the pilot's sitting posture ? Short description about the ground where the pilots fell down.

About injuries: Was the pilot wounded through the ejection ? What kind of injuries he had and, under his personal viewpoint, in which moment of ejection he would have been injured: Egress, landing or both. Duration of hospital care and grounding. Finally later flying status.

Pilot's post-accident behaviour : physical or mental sequelae, lost of motivation for flying duties. Pilot's opinion about necessity of training in ejection seat simulator and parachuting training. And finally, some questions about meteo and personal crewmember's observations.

RESULTS
This study includes 20 ejections. One of the 20 pilots, successfully ejected twice. 17 pilots survived and 3 pilots were killed. All ejections were premeditated, after structural/mechanical failure or pilot's loss of control. Although some ejections were in two ejection-seat aircraft, it has been considered as two different ejections.
All pilots ejected were healthy and fulfilled medical criteria for flying duty. Data about age, weight, stature and flying hours are showed in Table I.

Emergencies preceding ejections: We have considered three kinds of emergencies: Technical, Collisions and finally Loss of Control.
Regarding Technical Failures, we have split each group considering the former failure; as follows:
A.- Fire or Explosion.
B.- Flight Control System failures which enclose all primarily problems about electrical or hydraulic systems affecting the ability to control aircraft. When the electrical or hydraulic failure was due to an engine failure, the case was transferred to group D.

C.- Structural failures, (that were due to fatigue of materials).
D.- Engine failure, considering basically engine flame out.
Regarding Loss of Control, we have divided it into two subgroups: loss of control at low speed and low altitude, and loss of control at high speed and high altitude. All the incidents at high speed and high altitude occurred when the aircraft was flying outside the envelope of its aerodynamic limits. See Table II.

Review of all cases through the different phases of ejection:
In 20 ejections studied, there were 17 landings on the ground and 3 of them were landings on water. All ejections were over unpopulated areas.
17 pilots survived, but 60 percent of them were injured. 41 percent of the pilots that survived accomplished the ejections with serious injuries (7 out of 17), and pilots with only trivial injuries were 29 percent (5 out of 17), as shown Figure 1.

1.- Starting ejection: In Case number 6,in which the pilot was killed, all parameters about the moment of ejection are unknown. Regarding the remaining cases data are as follows:

1.1.- Control of the aircraft: At the moment of ejection, only 4 pilots had total control of the aircraft and all pilots were alive, in 15 ejections the pilot had no control of the aircraft, and 2 pilots were killed. See Figure 2

1.2.- Altitude of the aircraft: In the 4 ejections in which pilots had control, only 1 took place at very low altitude, less than 200 feet. The pilot survived. There were 3 more ejections at low altitude,in which pilots lacked aircraft control, from these only 1 pilot survived. The 16 remaining ejections, were at altitude ranging from 1000 ft to 14.000 ft. See Figure 3.

1.3.- Attitude of the aircraft: Even though the pilot had no control in five out of the 15 ejections, the aircraft behaved normally without changes in its attitude. The remaining ejections, were made from more or less violent diving or tumbling the aircraft. See Figure 4.

1.4.- Speed of the aircraft: All ejections were made at speeds ranging from 150 to 250 knots, except Case number 12 which was made at 350 knots. See Figure 5

1.5.- G forces load: All aircrafts involved in ejections were under 1 G, except 6 cases which supporting loads of Gs ranging from 1 negative G to 4 negative Gs. See Figure 6

1.6.- Sitting posture: Most of the pilots used the prescribed ejection procedures, with a proper sitting posture, excluding Cases 7, 19 and 20 which were unknown. See Figure 7. Only 3 pilots declared that their posture on the ejection seat was absolutely inadequate: The former pilot suffered a structural failure. His aircraft became uncontrollable after that. Suddenly it began spinning at 4 negative Gs, and consequently the pilot started his ejection without any visual reference. The second pilot, while flying a simulated combat, did a manoeuvre because, the aircraft was outside the envelope of its aerodynamic limits, and it also began spinning with negative Gs. The third pilot, we mentioned before, used all emergency procedures, but his aircraft flight manual in the chapter dedicated to the ejection seat, it showed the firing handle cable length longer than the one that was actually set in the aircraft, and when he pulled up the firing handle, located between his knees, the rockets ignition took him by surprise, so he egressed in wrong posture. Finally, 2 more pilots thought that their sitting posture might have been inadequate.

2.- Egress and parachute descent:
There were no major problems in these phases. Both were attained in all cases without difficulties, except in 2 cases where ejections were at a very low altitude. Both ejections were outside the design envelope of the escape systems, and the parachutes were not deployed. Concerning remaining ejections, not one pilot had contact between the parachute lines and legs or arms, and the deployment of parachute was perfect in all cases. There were slightly problems as back pains, haematomas etc. Only in one case, the helmet was lost. About 30 % of all ejectees had a limited chance to prepare for landing, due to injuries, or a parachute descent of only a few seconds.

3.- Landing: There were 3 landings on water, with temperature ranging from 12º to 22º C, (average of 17º C). All pilots used automatic life preservers that inflated correctly. Remaining landings were on the ground. One pilot, who had lost his helmet, was caught in a tree and remained hanging near the ground until he cut the lines. He was slightly injured on his face. Another one was entangled in the retention strap of his survival kit. 3 pilots were killed: 2 of them due to failure of deployment of the parachutes. One hit a tree trunk, after loss of control during landing procedures, just before the man-seat separation phase was completed, the other hit the ground. The third pilot was dragged away by high wind.

4.- Survival: Out of 14 successful ejections on land, in only 3 of them, were the pilots unable to be active: Cases 3, 7 and 8. The remaining situations were generally uncomplicated. Out of 3 successful ejections on water, only one pilot used his liferaft, this was because his rescue team arrived about 30 minutes after he reached the water.

5.- Rescue: All pilots were rescued within 3 hours after landing. 2 out of 3 pilots who were caught in the water were rescued by helicopter within the following 30 minutes after their mishaps took place. The third was rescued inmediatelly by a fishing boat. Its crew saw his parachute descent towards the sea. Most of the 14 pilots who landed on ground, were also rescued by helicopter, and no medical treatment was given to them by rescue teams. Three non injured pilots were helped by people and were taken to the nearest town.

Hospital care: Each and every pilot that survived was examined at the hospital inmediatelly after their rescues. 2 or 3 hours after their physical examination, that included X-Ray, 8 pilots left the hospital and resumed flying duties the very next day. All of these pilots, but one, kept on flying normally. The reason was that the latter suffered from back pain during his first flight, because of that, he was medically disqualified for flying for 3 more days. The remaining pilots, 9 out of the total, were hospitalized for time ranged between 2 days and 45 days. See Figure 8. They resumed normal flying duties after their discharge from hospital. It took between 1 week, and 6 months. Only one pilot, Case number 7, with right leg fracture, was classified as definitively removed from flying status. See Figure 9.

Review of injuries: 4 pilots suffered spinal fractures: Cases numbers 1, 9, 12 and 18. 3 out of them had fractures in levels T-11, T-12, L-1, with moderate compression, except in Case number 9, who had a fracture in T-12 including 25 percent of vertebral body crushing. The fourth pilot suffered a fracture in his coccyx. It is probable that most of these fractures were due to ejection forces in combination with wrong sitting postures. Out of 4 pilots, only one, Case number 1, had declared that his posture was inadequate. However, later investigations about cases 9 and 12, showed that their back could have been slightly separated from the seat at the moment of egress. In Case number 18, coccyx fractured, the sitting posture was good and the etiology of fracture was unknown. The legs of 2 pilots were fractured. One of them entangled in his survival kit at the moment of landing, and he suffered several fractures in both legs. The other had two fractures in his right leg probably due to both, imperfect landing technique and excessive weight. This pilot, after being discharged from hospital, was removed from flying status. One pilot suffered a pneumothorax in both his lungs. No rib fracture was found. In addition, he had several petechiae in his upper half body and specially a great conjunctival haemorrhage in both eyes. Probably all these injuries were due to dynamic pressure. There was only one pilot whose joints were injured caused by wrong landing. His left ankle was the joint injured. There were 2 pilots with minor fractures: One in his foot, and other in his hand. Regarding skin injuries, 7 pilots had scratches, haematomas etc.. the most frequent sites of injuries were the shoulder due to harness compression, the face caused by the oxygen mask, and the lower legs. And finally, 4 pilots suffered from muscle soreness, especially neck pain, probably due to ejection forces or none perfect landing. See Figure 10.

Post-mishap behaviour: There was not a survived pilot with physical sequelae except Case nº 7. Regarding psychological sequelae, among all pilots that successfully ejected and resumed their flying duties, 3 declared: that after the mishap they felt more confident about flying than they were before, so they trusted their ejection seats now. This opinion is often found among pilots that were not injured. However, most pilots consulted, declared that their attitude concerning flying had not changed after their mishap. Only 2 pilots had psychological problems: One of them was removed from flying status due to his injuries. The other one, after his total recovery, flew for some months the same type of aircraft. Nevertheless his psychological problems increased, so he was stationed a different air force base and he continued flying a different type of aircraft. Nowadays, he still recalls his mishap frequently. As consequence of that his flying activity is dying down. Probably we have more pilots with slight psychological problems, but they are not shown.

In our inquiry, sent to pilots, we were searching their opinion about two types of training: Ejection seat simulator training, and parachute training just from the tower. Pilots's opinions are very significant. Regarding ejection seat training, 65 % of pilots claim that it might be positive for the completion of their professional training, being especially concerned about adopting the right posture. Remaining 35 % declare that this not improve their standard training.

See Figure 11. On the other hand, regarding parachute training, (3 none injured pilots had accomplished several parachute jumps before their mishap), 88 % agree in the necessity of the parachute training tower, because that might improve their landing techniques. Only 12 % answered negatively when asked about this matter. See Figure 12.

DISCUSSION: The present study analyzes the medical consequences of ejections in Spanish Air Force pilots. Data referring to aircraft has helped us to understand how the ejection took place, but our aim is not to analyze how nor why the mishaps happened. The most important problem in flight is the pilot's situation awareness. After his former analysis of the problem, and perhaps several attemps in emergency situations, the pilot decides to egress. In addition we have no doubt about the many important factors surrounding pilots. Their selection, training, experience and psychophysical condition may modify the result of ejection. For example in two out of the three fatal ejections discussed in this paper, it is possible to blame the pilots' failure to identify and handle the emergency in due time, because the final cause that led to ejection was place out of the seat safety limits. Nevertheless, the pilots may have some time to prepare the ejection, injuries may occur either in the egress or in the landing phases (1, 2, 3, 4). So we must consider two aspects of their training: Sitting posture and landing technique. Five pilots were injured by inadequate sitting posture. Most authors agree to point out that posture is the most important factor to avoid spinal injuries, (1, 2, 5), even when the Dynamic Response Index of the seat is high. In our study, we have found a significant relationship between sitting posture and the number of injured pilots: 83 % of the pilots with adequate sitting postures were not injured, while 80 % of the pilots with inadequate postures suffered from some injuries. See Figures 13 and 14. We agree also with other authors, (2, 5), on the percentage of injuries and its more frequent location at low thoracic spinal levels. Regarding injured pilots at the landing phase, our conclusions are similar. See Figure 15. We have found 7 injured pilots and one pilot killed in that phase. They made 58 % of the total injured pilots. The pilot who was killed, suffered fatal injuries when he was dragged away by violent wind. Probably he was unconscious and unable to control the parachute. Concerning these pilots, we should consider all their injuries as the product of incorrect landing techniques (3, 4), and in one case, the combination of both: incorrect technique and excessive body weight. In summary, after this study, we can presume that both types of training: ejection seat simulator and parachuting tower may have decreased significantly the number and seriousness of injuries during ejections. In addition, it is necessary that pilots begin to fly again as soon as possible after a mishap or total recovery, in the case they had injuries. Consequently they can avoid psychological troubles that often appear when pilots resume their flying duties too late.

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TABLA I

DATA OF PILOTS

	Age	Stature	Weight	Fl.Hrs
Max	47	190	90	4700
Min	23	166	60	280
Avg	32,8	174,4	72,8	2003,5
Std	7,28	6,71	8,41	1386,01

Lt.Col. García Alcón

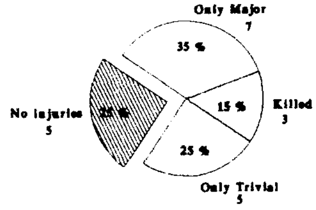
TABLE II

KIND OF EMERGENCY PRECEDING EJECTION.

TECHNICAL FAILURE

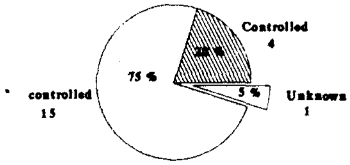
A.- Fire or Explosion................................	3
B.- Control system failure...........................	3
C.- Structural failure...............................	3
D.- Engine flame out.................................	2
COLLISIONS	
With Bird..	1
LOSS OF CONTROL	
At low speed and altitude............................	2
At high speed and altitude...........................	6

Lt.Col. García Alcón



Injuries

Figure 1



Aircraft Control

Figure 2

Starting ejection

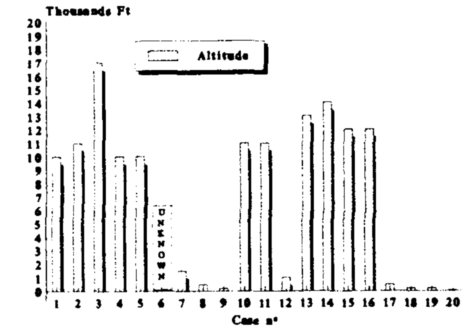


Figure 3

Starting ejection: aircraft attitude

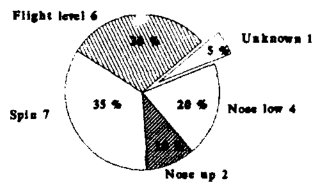


Figure 4

Starting ejection

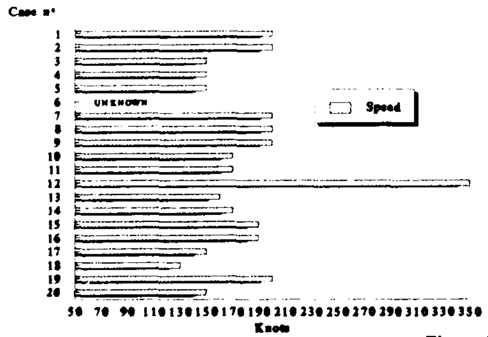


Figure 5

Starting Ejection: G loads

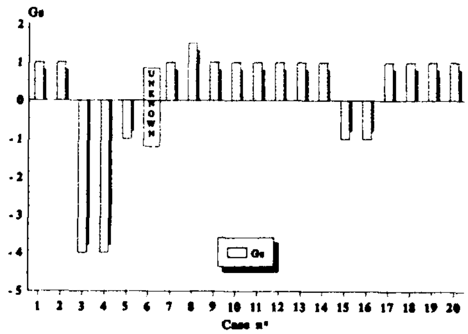


Figure 6

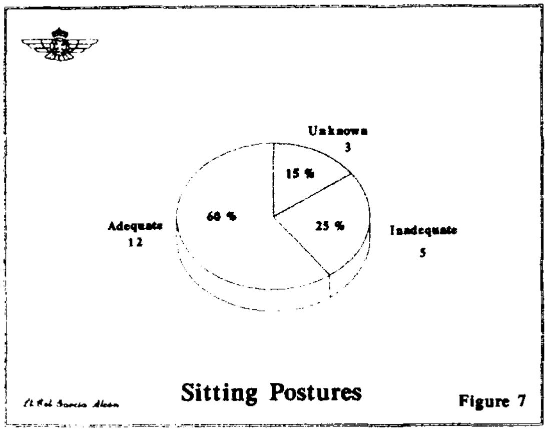


Figure 7

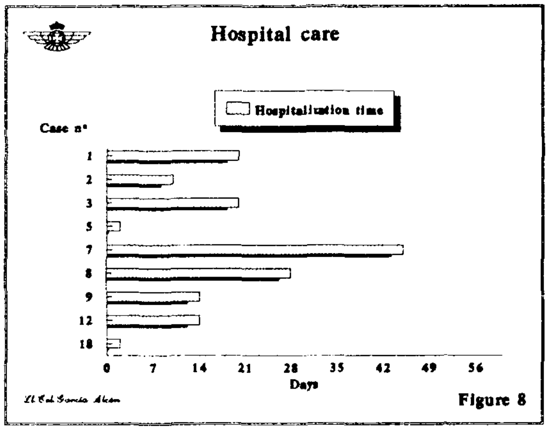


Figure 8

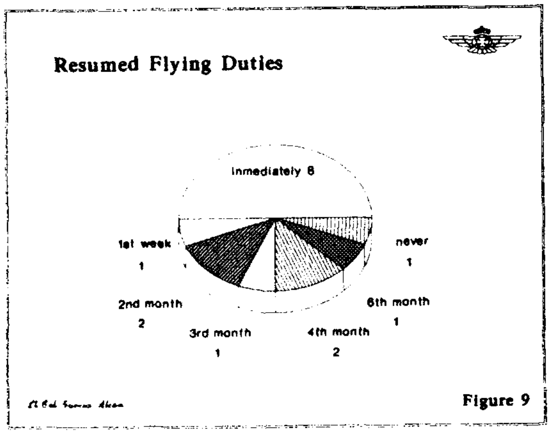


Figure 9

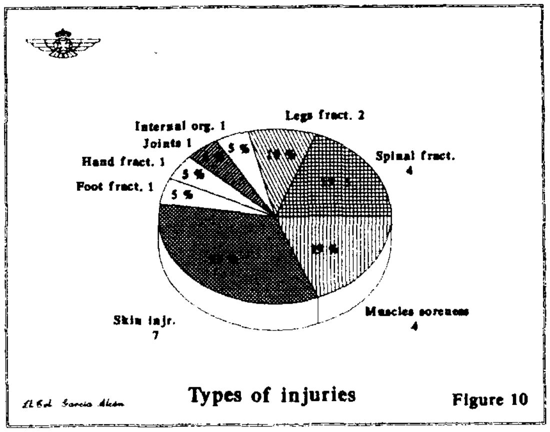


Figure 10

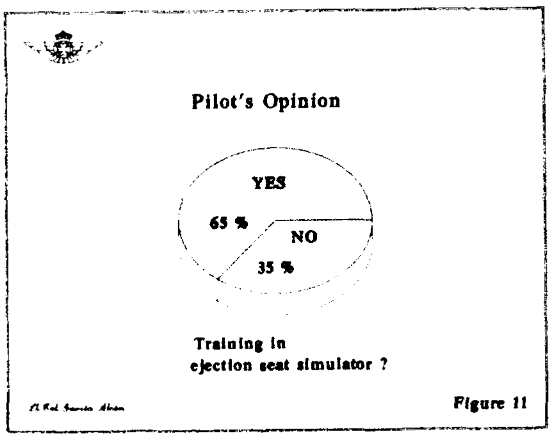


Figure 11

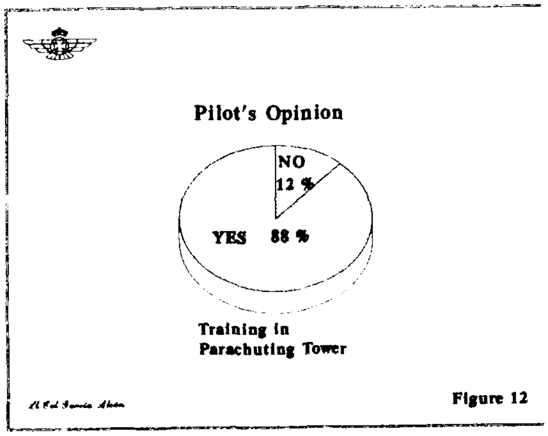


Figure 12

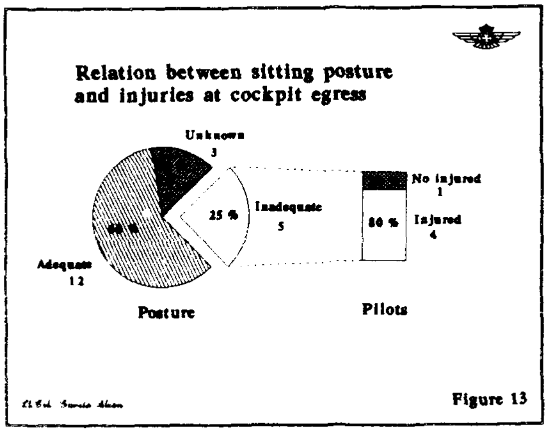


Figure 13

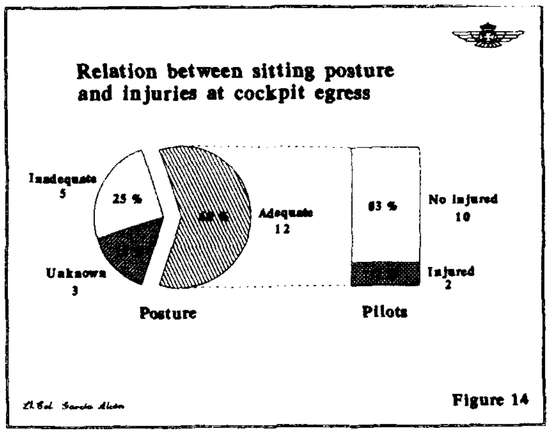


Figure 14

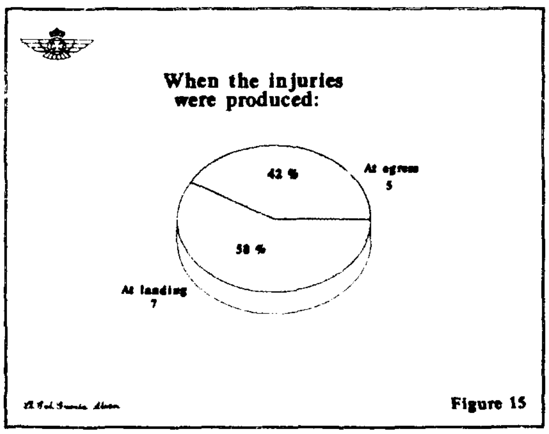


Figure 15

Towards an Integrated Approach to Proactive Monitoring and Accident Prevention

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1. SUMMARY

Most traditional accident prevention programmes are based on information gleaned from accident research. While acknowledging the contribution from this approach, two difficulties can be identified. First, many accidents may be the product of a unique combination of circumstances. Second, the whole process is 'reactive'. In contrast, the research initiative reported here begins with the premise that the components of any organisation may already hold much information which could be relevant to safety research and which could be used 'proactively'.

The approach seeks to exploit the fact that many organisations operate a 'closed system' whereby they control and monitor the throughput of personnel with some degree of objectivity. The research programme described is essentially data-driven and focuses on identifying sources of information concerning flying behaviour which could contribute to flight safety and accident prevention. Thus the programme seeks to establish points of 'proactive intervention'.

The community involved in the study is the UK Army Air Corps (AAC). The research programme has examined aspects of the selection, training and operational sub-systems of the UK Army helicopter community, in addition to traditional accident information.

A novel feature of the methodology outlined in this programme is that each of the areas can be considered as stand-alone modules, capable of providing useful management information in their own right. Taken together, they represent a powerful and integrated approach to an organisation's flight safety and accident prevention programme.

2. INTRODUCTION

Traditionally, accident prevention has begun with the analysis of accidents. The purpose is both to provide an understanding of the underlying causes and to furnish evidence which can be used to prevent a recurrence. The focus therefore tends to be exclusively on the specific events surrounding the accidents themselves. Investigations seek to establish precisely what occurred, and subsequently by highlighting aspects judged to be undesirable, attempts are made to influence the future behaviour of the community via a 'lessons learned' approach.

Valuable though this approach is, it suffers from two fundamental weaknesses. In the first place, many accidents are the product of a unique chain of circumstances, with perhaps little that can be generalised. In the second place, it is essentially a 'reactive' process ie it occurs after the event.

Also, to concentrate exclusively on the information contained in accidents would appear to overlook other potentially fruitful areas. For instance any organisation which controls the progression of personnel through various component stages by means such as training and/or examination, is likely to possess other data which could be employed to improve flight safety. This is especially likely to be the case the more the organisation represents a 'closed system', as is the case with most service situations.

3. AIM

The aim of the project is to examine the various component parts of the UK Army Air Corps to identify sources of data which might serve as potential points of 'proactive intervention'. As the programme is ongoing, the aim of this paper is to provide a brief overview of the methodology, drawing upon illustrative examples where appropriate to convey a flavour of some of the research.

4. METHOD

4.1 The Organisation

A simplified overview of the throughput structure of the UK Army Air Corps shows how potential pilots pass through various stages of selection and training before joining a unit. Figure 1 shows that there are a number of component 'modules' which can be identified as potential sources of data to supplement the usual information obtained from accident analysis. Progress in investigating each of these modules is summarised below.

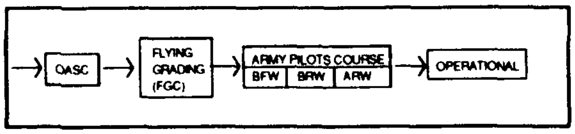

Figure 1. AAC Throughput

4.2 Selection

The AAC takes candidates for pilot training from both civilian life and the services. Initial stages of selection involve aptitude testing at the Officers and Aircrew Selection Centre (OASC) at RAF Biggin Hill. There, candidates perform a number of computer-based tests of psychomotor ability, cognitive functioning and instrument comprehension (although the number and nature of these tasks is currently under review). Civilians also have to pass a Regimental Board which assesses their general suitability.

Under normal circumstances successful candidates are then sent on a flying grading course (FGC). Unlike the initial computer-based selection tests which are designed to capture essential elements of required skills, flying grading consists of 13 hours of actual flying in a fixed wing aircraft. During this period experienced instructors assess the candidates' pilot aptitude. Those successful at this stage are awarded a place on the army pilots' course (APC).

With regard to this module, the research programme is engaged in searching for the best predictors of success, and *in identifying failure at the earliest opportunity*, thereby ensuring the most cost-effective selection system and a safer pool of pilots. Initial findings indicate that 'real' flying (as represented by the flying grading course) is a much more powerful indicator of success on the pilots' course than the computer-based tests alone. Calculations based on a sample of almost one thousand trainee pilots showed that the APC pass rate was 71.02% and the failure rate was 26.69%. However when the sample was broken down into those who went through flying grading prior to the APC and those who did not, it revealed that the pass rate in the former was 78.7% while in the latter group it was only 66.5%. Table 1 shows the numbers involved expressed as a Chi square contingency table, with the expected values in brackets. Using Yates' correction, Chi square = 15.597879. The result is significant ($p < 0.001$, $df = 1$).

		APC OUTCOME		
		Non FGC	FGC	
APC	PASS	403 (429.6)	281 (254.4)	284
	FAIL	188 (161.4)	69 (95.6)	257
		591	350	941

Table 1: Contingency Table of Training Outcomes

This may not be particularly surprising. However, expense and the limited number of FGC places would prevent it being used as the sole means of aptitude selection. In any case, although the test battery correlates relatively weakly with the final outcome of the APC, it correlates more strongly with the FGC outcome. It therefore does perform the function of a useful screening process. The selection data is currently being computed with corrections for the range restrictions which occur as a consequence of the progressively smaller numbers advancing through the system.

When the current exercise on this phase is complete, it will furnish additional information not previously available on the predictive power of variables such as age, rank and the relevance of previous experience. This area will be worthy of further study in the future given that OASC are to introduce additional tests into the battery. Finally, a finegrain validation exercise of the new selection battery will be conducted in conjunction with the next module covering training.

4.3 Training

From the outset of the project, one fundamental aim was to make the exercise data-driven wherever possible. This search for quantitative evidence prompted an examination the training area where a large amount of data was known to exist. This provided abundant evidence of both success and failure at 'real' flying tasks.

Following successful selection and flying grading, candidates on the army pilots' course progress through three phases of training: basic fixed wing (BFW), basic rotary wing (BRW) and advanced rotary wing (ARW). Throughout each of these phases their progress is recorded in a training record folder. On each sortie flown students are assessed against 21 basic abilities. For each of these, performance is graded on a four point scale, and the sortie itself is given an overall grading according to the same scheme. This information is colour-coded onto a summary sheet, (blue =above average, green = average, brown = below average and red = fail). This multi-coloured matrix provides the instructor with an instant visual picture of the student's progress. (Written reports on each sortie supplement this summary should the instructor wish to consult more detailed information on specific exercises). However, until the current research, these records had been employed solely to check on the progress of *individual* students. Even then none of the information was employed statistically. There were therefore no scores which could be used to illustrate norms or averages for groups of students.

Two approaches have been adopted with regard to these data. The first attempts to produce a tool which could be of use to management in general and the instructors in particular. The second represents the beginning of a research effort to examine the concepts underlying the training/assessment system with a view towards strengthening the appraisal process.

4.3.1 *Underlying Concepts - Management Tool*

The initial search for consistencies or patterns was done by computing the brown and red gradings (ie scores representing below average performance) for a sample of student pilots. Figure 2 shows typical 'Error Rating Profiles' (ERPs) obtained from such a sample when the scores are calculated in this way. (The term 'profile' here is not meant to imply a mathematically continuous function, it is merely a convenient descriptive label). It is immediately obvious from Figure 2 that there is a regular pattern to such a function, with most of the errors judged to have been committed against a sub-set of the basic abilities. It transpires that this pattern is non-random, and although there are subtle differences for particular types of sortie and different phases of the course, these too would appear to contain consistencies. With very little effort therefore, a tool can be made available to enable instructors to compare any student's performance with group norms from any phase of the course. Such a pragmatic technique could be of particular help to new instructors.

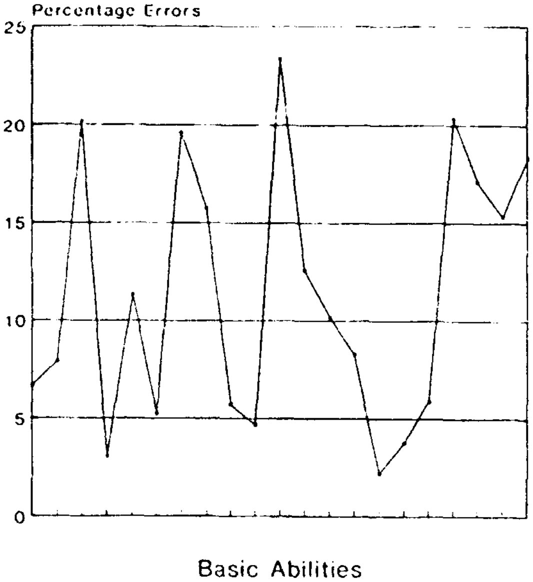

Figure 2 Error Rating Profile

The extent to which such patterns can be used in a predictive fashion is explored in more detail elsewhere (Ref 1). Suffice it to report here that aspects of these early patterns appear to be potentially enduring indicators of performance well beyond the APC. For instance, during the course of this work the senior author was contacted by a commander in the field who wished to discuss the flying performance of one of his pilots which he considered to be unsafe. When the training records of this pilot were subjected to 'Error Profile' analysis it was found that the functions obtained were more closely related to the average fail function than the average pass function.

4.3.2 *Underlying Concepts - Appraisal System*

The other main thrust of the research work on the training area has concentrated on laying down the groundwork for a more objective appraisal system. This has begun modestly by attempting to uncover precisely how the various basic abilities combine when subjected to factor analytic techniques. Table 2 illustrates this with the results of a principal component analysis carried out on each of the three phases of the APC. This shows that the basic abilities tend to reduce to three or four core sets of elements, with some subtle differences between the phases. Factors are listed according to their weightings.

The next stage of this work is being conducted on a number of features, including addressing questions of content validity. For instance clarification is required on precisely what the instructors mean by some of the terms, and what specific behaviour constitutes a pass or fail grade on these.

(a) BFW

Factor	% Variance Explained	Cumulative %
1	56.7	56.7
2	12.0	68.8
3	10.3	79.0
4	7.2	86.3

Factor 1	Factor 2	Factor 3
Flexibility	Lookout	Checks
Stability	Attitude	Cockpit Managt.
Anticipation	R/T	
Accuracy	Rule Following	Factor 4
Awareness		
Recall		Rule Following
Div of Attention		Obs a/c Limits
Co-ordination		Captaincy
Visualisation		
Captaincy		

(b) BRW

Factor	% Variance Explained	Cumulative %
1	57.9	57.9
2	12.5	70.4
3	8.2	78.6

Factor 1	Factor 2	Factor 3
Div of Attention	Captaincy	Rule Following
Flexibility	Attitude	R/T
Anticipation	Stability	
Awareness	Obs a/c Limits	
Control Action	Lookout	
Co-ordination		
Recall		
Visualisation		
Accuracy		

(c) ARW

Factor	% Variance Explained	Cumulative %
1	51.0	51.0
2	13.5	64.5
3	5.9	70.4
4	5.4	75.5

Factor 1	Factor 2	Factor 3
Div of Attention	Crew Co-operation	Cockpit Managt
Recall	Briefing	Flexibility
Accuracy	Captaincy	
Control Action	Planning	Factor 4
Co-ordination	Lookout	
Awareness		Attitude
R/T		
Visualisation		
Anticipation		

Table 2: Principal Component Analysis Performed on (a) Basic Fixed Wing, (b) Basic Rotary Wing and (c) Advanced Rotary Wing Phases of Training

Concerns such as these are being pursued with the aid of subsidiary semi-structured interviews and follow-up questionnaires.

Finally, the apparent differential value attached to a sub-set of the basic abilities has raised the opportunity of attempting correlations between the selection battery and specific capabilities. This, plus examination of the records of those suspended from the course, affords a much more finegrain validation exercise than has ever been possible before. Such analyses will be particularly important in the development and validation of new tests.

4.4 Operational Aspects

The term operational is used here to cover all those who have passed the APC and have now joined units in the field - essentially all line pilots. Of these, some will return for further training such as conversion courses onto other helicopters, or to undergo aircraft commanders' courses. With the exception of these courses (which are considerably shorter than the APC and where the data is particularly sparse), there is little in the way of data which can be tapped in the same way. The only other recorded information is that which is available from the six-monthly checkrides on pilots carried out by standards officers.

Because of the paucity of objective data in this area techniques have been employed to elicit subjective comments and opinion. Confidential semi-structured interviews have been conducted on instructors, line pilots and aircrewmen of differing experience levels. Such areas as personal attitudes, motives and particularly operational pressures, are being probed in an effort to provide general views on the operations area. The information obtained from this phase of the project, although less easy to quantify than the rest of the data to date, helps to define the social and organisational ethos. Such material is of vital importance because flying skills are not employed in a vacuum. This area of the project therefore attempts tap the organisational culture and to put the flying behaviour into a realistic context.

4.5 Accidents, incidents and near-accidents

Finally, the area traditionally associated with accident prevention requires to be addressed - ie accident analysis. Typically such analyses reveal that human error is responsible for the largest proportion of accidents (eg Ref 2). In the context of this programme, a database of accidents is currently being examined to establish the accident profiles, and to investigate what relationships exist between these and the information elicited by other parts of this research. Particular consideration is being devoted to establishing which aspects are attributable to flying errors (and may therefore reflect the error profiles or the factor analysis performed on the training phase), and which are the product of particular pressures (and may be supported by the material obtained in the operational interviews).

However accident analysis is only ever likely to be touching the exposed tip of the 'error iceberg'. Clearly a great many accidents are only narrowly avoided, some knowingly, others perhaps not. The former may be tapped by other methods such as incident analysis. Here only the semantics of a categorisation scheme may separate an incident from an accident, eg by the degree of damage or injury sustained.

Many incidents which were close to becoming accidents may never be reported because of the possible attribution of blame. Yet such occurrences are equally valuable sources of material, both in helping understanding, and in providing additional information to assist prevention. In order to tap these events, organisations need effective confidential reporting systems. Military systems typically do not favour such schemes. At senior levels they tend to be frowned upon as potentially subversive because they appear to offer a mechanism which could undermine the chain of command. At the level which represents the potential source of reports, there is often considerable scepticism over confidentiality. This is particularly the case in small organisations where it is felt that divulging detailed information will automatically identify the perpetrators to the community, even if names and units are withheld from general release.

Within the AAC, the first trial year of a new confidential reporting system has just been completed. The essential difference from the previous, (tri-service system), is that all reports are now sent direct to the Head of the Human Factors Unit (the senior author), who alone retains information about the report's originator. As a CIVILIAN adviser this position is clearly perceived as independent of the chain of command. Thus far the experiment appears to have been successful, with a fourfold increase in reports, and information on a variety of topics including some dangerous flying practices.

To the extent that such reports can emanate from anywhere in the system (eg operational or training environments), they provide opportunities to tap the social, managerial, command and organisational pressures being exerted.

5. CONCLUDING COMMENTS

The research programme outlined here has argued that programmes of accident prevention ought not to focus exclusively on accident analysis for their material. Organisations are made up of a number of components which are likely to contain information which could be relevant to proactive approaches. The case has been made using the example of an ongoing research programme being conducted on the selection, training, operational and accident databases of the UK Army Air Corps.

The approach demonstrates that each research module is capable of yielding valuable information to guide management. However as the components are also interdependent, it is argued that only by taking a total systems approach is it possible to provide an 'integrated whole' which is greater than the sum of its parts. Figure 3 summarises this integration and identifies the main areas of proactive intervention.

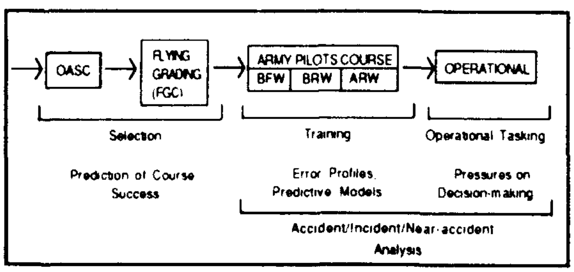

Figure 3. AAC Throughput, Sources of Data & Points for Proactive Intervention

6. ACKNOWLEDGEMENTS

This work has been carried out with the support of Aviation Standards branch of HQ DAAC. The co-operation of Army Air Corps personnel is gratefully acknowledged.

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Accidents and Errors: A Review of Recent UK Army Air Corps Accidents

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1. SUMMARY

Aircraft accidents can be categorized in a number of different ways (eg aircraft type, amount of damage, nature and severity of injuries sustained). Similarly, causation can be attributed to a variety of different factors (eg aircrew error, technical failure, operational hazard). Of all the labels used in such schemes, the one which consistently dominates the list of causes is that referred to as 'human error'. In this respect the accident statistics of the UK Army Air Corps (AAC) are no exception. However a label such as 'human error' is not particularly enlightening with regard to accident aetiology, nor does it immediately suggest obvious areas for remedial action. To satisfy these requirements, more detailed categorization schemes are necessary. Three such schemes were applied to a sample of recent AAC accidents for which human factors investigations were available. Two of the schemes (Feggetter, Ref 1 and Chappelow, Ref 2) had been developed within the field of aviation accident investigation while the third (Reason, Ref 3) represented recent developments within cognitive psychology. To date, around half of the accidents held in the database have been subjected to analysis. Preliminary results suggest that while all the schemes were useful, one particular scheme (Ref 2) was easier to implement than the other two, provided a good understanding, and indicated areas for remedial action. The exercise is being extended to cover a larger sample.

2. INTRODUCTION

2.1 The Army Air Corps

The UK Army Air corps (AAC) currently runs a fleet of well over 300 aircraft. The fleet is predominantly made up of rotary wing (RW) craft, with Gazelle (161), Lynx (109), and Scout (33) helicopters. In addition to these, some 22 Chipmunk fixed wing (FW) aircraft form an essential part of the training squadrons, and a further 7 Islander aircraft complete the fleet. Approximately 100,000 flying hrs are flown each year although no details are available on how many landings and take offs this might include.

2.2 AAC Accidents - Some Basic Statistics

The last review of AAC accidents (Ref 1) concentrated on medical and survivability aspects of rotary wing accidents in the period 1977 to 1982. The current survey covers accidents up to and including 1991. It covers both FW and RW and concentrates on human factors aspects.

2.2.1 *Accidents 1965-1991*

For the present purposes an accident is defined (according to JSP 318) as where the aircraft sustained category 3, 4 or 5 damage (where cat 5 represents scrap value only), or where fatalities or major injuries have been incurred.

(This scheme has been altered recently to exclude cat 3, but the old scheme was in operation for all the accidents examined in this review). For the current review all accidents involving hostile action have been excluded. Figure 1 shows the AAC accident rate expressed as a function of 10,000 hrs flying (some 281 accidents in total) over the last 25 years. Both fixed wing and rotary wing accidents are included in these data although FW only accounts for 11.03% of the total, and 6.35% of the accidents in the last decade.

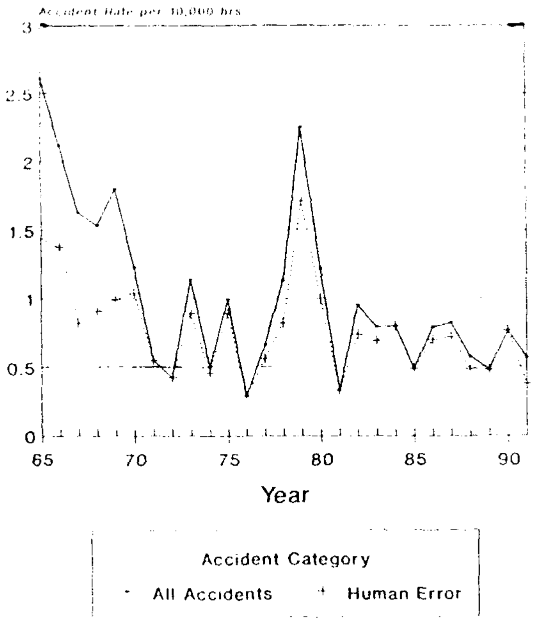

Figure 1 Accident Rate - Total Accidents and Human Error Accidents

The solid line in Figure 1 shows a steady decline in AAC accidents from a peak during the sixties, and with the exception of an aberrant peak around 1979, the curve appears to approach asymptote just above .5. The broken line in Figure 1 represents those accidents caused by human error. This also shows a decline throughout the period (again with the exception of 1979), although it does not parallel precisely the decline for all accidents. Indeed it is clear that while the total accident rate has decreased, that proportion of accidents attributable to human error has actually increased during the period. This is illustrated in Figure 2 which shows that human error accounted for some 60% of all accidents during the late sixties but that this proportion had risen to around 90% during the last decade. By way of partial explanation, it should be noted that the composition of the AAC fleet has altered during the course of the period under review. One fundamental cause of the early, 'unavoidable', high accident rate was the large number of technical/mechanical faults which developed with earlier, less sophisticated (piston engine) types of helicopter (eg Skeeter). The current fleet of turbine powered aircraft have proved to be much more reliable and less likely to develop catastrophic mechanical failure.

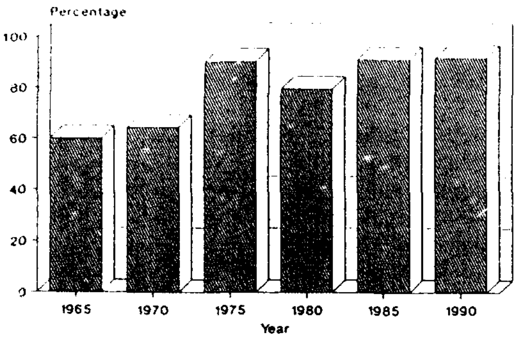

Figure 2. Human Error (HE) Accidents - HE Accidents as a Percentage of all Accidents

For instance there were 29 rotary wing accidents categorized as technical failures during the period 1964-1970, and while the comparable figure for FW during the period was 4 (22.83% and 3.15% of all accidents respectively).

2.2.2 Accidents 1982-1991

Figure 3 shows accidents for the last decade broken down into their major cause categories. This shows aircrew error as the largest single category. This agrees with the previous survey (Ref 1) and indeed appears to be the case whatever time periods are selected. When the AAC acquired more sophisticated aircraft such as the twin-engine Lynx, fears were expressed in some quarters that benefits from the more powerful aircraft might be offset by difficulties in servicing a more complex machine. At first sight this would appear to receive support from Figure 3 which shows a very large proportion of accidents due to servicing error. However, closer inspection of the accidents making up this figure reveals that a very large number were actually 'ground accidents'. These occurred during servicing, but were caused while the aircraft were being moved, either in or out of hangars, from bay to bay within the hangar, or on and off jacks. Therefore while all these accidents represent 'legitimate' human error accidents caused during the supervision of service-related activities, the statistics do not reflect the complexity of servicing operations. Indeed when these ground accidents are removed from this category, the figure drops to 2.75%, a figure which is almost identical to the 2.55% attributable to servicing error during the period 1965-1979 and only a slight increase on the 1.59% recorded during the period 1965-1970.

When added together, the aircrew, servicing and the 'other' error categories make up the total attributable to human error, with the largest category aircrew error as noted above. However such a statement is of little practical value. By itself it does not assist with unravelling the

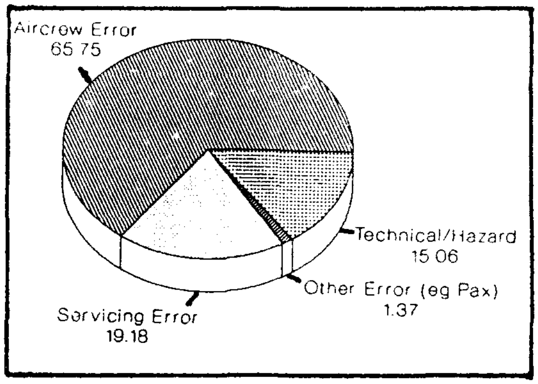

Figure 3. Accident Breakdown - Cause Code and Proportions

aetiology of what happened and why it happened. Nor does it help in suggesting precisely where remedial action can be applied. In order to resolve these questions, more detailed information concerning the accidents themselves is necessary.

Following the practice begun by the UK RAF, the AAC requested that Defence psychologists conduct independent confidential enquiries as part of the post-accident investigation process from the late 1970s. These human factors (HF) investigations draw upon a number of sources of information including confidential interviews with survivors, colleagues, witnesses and the chain of command; personal and training records of those involved; and examination of all relevant documentation. These investigations contain a vast amount of information which up until now has not been collated across accidents. In order to benefit from this detail in a way which could further understanding of the human factors underlying the accidents, some form of coding system is necessary.

2.3 Error Taxonomies

There are two problems with this. First there is no generally accepted taxonomy of error; most seem to have evolved to serve the need of the specific community with which they are associated. Second, even a cursory search of the literature reveals around 40 possible taxonomies which are currently in use (Ref 5). These vary from checklists containing more than 700 items (Ref 6) to those containing only three or four items (eg Ref 7). One of the principal problems in employing an example of the former is that one would need a vast database of accidents to be able to produce any meaningful trends. On the other hand very few categories would appear at least superficially to offer little more than the broad classification already available in Figure 3.

Three such schemes were selected for initial consideration (Refs 1, 2, 3). Two were devised by practising aircraft accident investigators (Refs 1 and 2) and therefore owe as much to their own personal experience as to knowledge already available in the literature. The third (Ref 3) was developed by an academic intimately involved with developing a theoretical basis for the understanding of human error, especially as it applies to major disasters.

The principal headings for all three schemes are listed in Annex A.

The first taxonomy under consideration here was proposed by Feggetter (Ref 1). [The same author went on to advance an intelligent-system-based approach, but this will not be addressed here (Ref 8)]. There are two principal strengths of Feggetter's original scheme. The first is that it adopts a 'total systems approach'. That is to say it includes such headings as 'life stress' events and personality as potential contributors to the accident milieu. The second advantage is that Feggetter's classification is linked directly to her development of a human factors checklist which she recommends be employed by the HF accident investigator during the inquiry, thereby ensuring a direct link between information collected and the categories used during encoding

The second classification scheme to be examined was devised by Chappelow (Ref 2) and was based on the retrospective analysis of a corpus of 149 HF investigations of RAF accidents, the majority of which he had carried out himself. During the analysis the scheme evolved in something of an iterative fashion. Although it shares a number of items with Feggetter's scheme, the principal advantage of Chappelow's coding system lies in the fact that it permits a hierarchy of attribution levels. First, there are predisposing conditions, labelled 'Aircrew Factors', some of which may be under the control of the individual while others may not. This category includes items such as personality and inexperience. Next, a number of items are deemed 'enabling factors', conditions which make it all too ea for errors to occur. These are labelled 'System Factors' and include ergonomics, training, and high workload. Finally, those errors committed in the immediate temporal zone of the accident are deemed 'Modes of Failure'. These include headings such as cognitive failure, inappropriate model and disorientation.

The third classification scheme selected for consideration is the generic error-modelling system (GEMS) developed by Reason. Although versions of this appear in earlier publications, the most elaborate exposition is given in his recent book (Ref 3). This scheme is an example of the most recent theoretical developments within the field of cognitive psychology by someone closely associated with investigating human error. Acknowledging a debt to the earlier models of Rasmussen, (Ref 9), and Rouse, (Ref 10), Reason attempts to present an integrated picture of the error mechanisms underlying action slips or lapses, and mistakes ie rule-based errors and knowledge-based errors. GEMS links these fundamental error types to the levels of performance with which they are associated. In this way, errors are treated as a natural component of human behaviour. Thus slips and lapses are associated with skill-based performance were typically smooth, automated and routine patterns of behaviour fall prey to failures of attention. Mistakes on the other hand are divided into rule-based errors and knowledge-based errors, both of which are seen as the product of problem-solving activity. In the former, matches with previous familiar patterns are attempted. In the latter mistakes are seen as the product of incomplete knowledge or faulty diagnostic logic.

3. AIM

The aim was to encode a corpus of HF reports according to the three classification schemes selected to determine their respective utility. The criteria employed to determine this were (i) the ease of the encoding operation, (ii) the extent to which common themes were uncovered and understanding advanced, and (iii) the degree to which they indicated remedial action.

4. RESULTS

The exercise proved to be more time-consuming than anticipated. To date around half of the accidents held in the database have been subjected to analysis. Results are therefore preliminary.

4.1 Accident Breakdown

Table 1 provides a basic breakdown of the 25 accidents considered to date. Scrutiny of the database has revealed that those identified as major categories are the same as would be indicated by consideration of all accidents on record. The sample can therefore be taken as being fairly representative. All accidents in the sample except for one, involved rotary wing aircraft; all refer to daylight accidents; and 60% involved the carriage of passengers.

By Phase of Flight	
Ground	4%
Take Off	12%
Transit	16%
Low Level	12%
Approach	5%
Hover	4%
Landing	36%
By Sortie Type	
Air Test	8%
Casevac	8%
Exercise	8%
Familiarisation	8%
General Handling	8%
Ground Incident	(not included)
Mountain Flying	4%
Training (unspecified)	24%
Transit	16%
Troop Insertion	12%
Other	4%
Environmental Conditions	
Strong Wind	28%
Overcast	12%
Raining	4%
Snowing	12%
Haze	12%

Table 1: Basic Accident Breakdwn for the Sample Examined

As can be seen from Table 1, the majority of accidents occur during phases where a high rate of information-processing is demanded of the aircrew. In terms of sortie type, training flights are most commonly associated with accidents, closely followed by transit flights and troop insertions. Strong wind is cited as the most common environmental correlate.

4.2 The Principal HF Categories

The human factors reports for the 25 AAC accidents were coded according to the three classification schemes outlined above. The principal human factors which were uncovered as a result of this exercise for each of the classification schemes are listed in Table 1. The figures refer to the percentage of accidents where that category was cited. Categories are not mutually exclusive.

Feggetter					
Attention	64	Habits	52	Speed and motion	40
Decision	64	Personality	52	Altitude	36
Perception	44			Training	44
Action	40				
Chappelow					
Lack of airmanship	60	Training	52	Inappropriate decision	68
Personality	52	Briefing	48	Overarousal	44
		Administration	44	Distraction	36
Reason					
Skill based	64				
Rule based	44				
Knowledge based	40				

Table 2 The Principal HF Categories Expressed as Percentages for each Classification Scheme

Most accidents revealed several human factors aspects and some revealed up to twelve contributory factors. To some extent, only a combination of all classification schemes appeared to do justice to some of the accidents. Clusters do appear to occur across the schemes. Thus the inappropriate decision category in Chappelow's system tends to be associated with the decision and action categories in Feggetter's scheme, and the knowledge and rule-based categories of Reason's classification. However a full examination of such considerations will have to await coding of the complete database. In the meantime a brief description of some of the major HF categories identified by this exercise, with illustrative examples, is given below.

4.2.1 *Decision-Making*

There appears to be a large number of situations where faulty decision making was involved. These also tend to be associated with lack of airmanship in Chappelow's scheme and/or personality. Examples of these would include poor choices of height, speed and route for the conduct particular manoeuvres; decisions to press on with a task or a manoeuvre despite contra-indications; or in the case of workshop personnel, the decision to cannibalise parts from different aircraft.

One further category of faulty decision-making lies at the core of another group of recent accidents. These involve instructors training students on exercises such as engine off landings (EOL), a practice which involves very small margins for error. Typically training and inexperience are also cited in these reports, not only against the student, but also against the instructor who in every case, had only recently qualified as instructor. The personality of the instructor also appears to be important, and those most vulnerable to the situation are those described as "very conscientious" or "keen for their students to perform well". Thus the naive instructor, anxious for his student to get maximum value from the lesson, fails to intervene to take control until too late in the manoeuvre. In an exercise with small margins for error, this degree of trust is clearly misplaced.

Reason's error classification shows that the most common error committed was that of skill based slips and that more than half of these were down to inattention. However it is also evident that a large number of faulty decisions were due to rule-based mistakes. These were more often due to the application of 'bad' rules, rather than the misapplication of good rules implicating both training deficiencies and disregard for regulations. Fewer occurrences of knowledge-based mistakes were judged to have been found in the accidents i.e. where the pilot engaged in slow serial problem solving activity.

4.2.2 *Personality*

The influence of personality is seen as very strong and appears in both Chappelow's and Feggetter's schemes. Where the scheme permits further links (Chappelow), this shows it has also been associated with a lack of airmanship, a disregard for rules and problems of crew coordination in a number of recent accidents. Personality features both in accidents where the event is linked strongly to an individual's cognitive style and in accidents where consideration of crew composition was important i.e (the interaction of personalities). A number of recent accidents have revealed difficulties with cockpit authority gradient (CAG). In contrast to more typical examples, these have revealed little or no cockpit authority gradient. Problems are created where both aircrew are well-known to each other and of comparable flying hours. The recipe for disaster is complete if a forceful but low-average ability handling pilot is paired with a quiet, non-assertive aircraft captain. This combination of circumstances has been associated with a number of recent accidents, and indicates that despite early hopes (Ref 4) and all its obvious benefits, there are also limitations to any two-pilot system.

4.2.3 *Training*

Training inadequacies feature prominently in both Feggetter's and Chappelow's schemes. Such deficiencies are also reflected in Reason's taxonomy as rule-based mistakes, showing up both as the misapplication of appropriate rules and the appli[illegible] bad rules. As might be expected a number of [illegible] inadequacies are highlighted in accidents with student pilots where their inexperience has been exposed. Other examples however include a group of accidents involving Lynx aircraft with high all-up-mass (AUM). These have revealed that many pilots are unfamiliar with the handling characteristics of such aircraft, especially when flown close to the edge of the flight envelope, and were therefore unable to calculate the increased margins for error required.

4.2.4 *Briefing*

In half of the investigations where briefing was cited as a factor, little or no briefing was given concerning the details of the sortie. This was typically because the task was so familiar that detailed briefing was deemed unnecessary. In many cases these sorties involved the carrying of passengers, often on familiarisation flights, and the flight merely 'evolved' in an ad hoc fashion. In around a third of the accidents, the inadequate briefing was associated with time pressures and insufficient slots between sorties. Paradoxically this was particularly true of training sorties. Here instructors' daily workloads were very high resulting in truncated periods for briefing, debriefing and report writing. In such cases, the administration category in Chappelow's classification scheme would also be implicated to indicate the system's contribution to the problem. For most of the remaining accidents, briefing was simply ambiguous or not sufficiently detailed to cover all eventualities. In one case, however, a briefing order suggested that a familiarisation flight should be injected with a "degree of excitement", thereby encouraging a particular style of flying.

4.2.5 *Miscellaneous Categories*

On the occasions when disorientation was mentioned, typically it was cited as a possible contributory factor, and usually in response to something else. For instance, in one case it was suggested it may have occurred as a result of unexpected handling of the aircraft. In two cases it was cited as possibly following a steep banking turn, while in another, whiteout conditions were implicated.

Overarousal features prominently amongst Chappelow's modes of failure. This term however, which refers to stress or alarm states, tends to be a reaction to a specific situation developing - such as an emergency - rather than occurring spontaneously.

Finally under this heading, and by way of comparison, it is interesting to note that unlike Chappelow's RAF database (Ref 2), the AAC database so far has revealed very few accidents associated with ergonomic problems. The same is also true for cognitive failure. Whether these indicate major differences between fast jet and rotary wing operations will have to await further study.

5. DISCUSSION

The corpus of HF reports on the AAC accidents examined for this review has revealed a number of recurrent themes. These are represented by category labels such as inappropriate decision, attention, perception training, briefing, administration, personality, habits and lack of airmanship.

5.1 General Comments

It is not an easy task to reduce the rich narrative of an accident report with many layers of interacting human factors to a collection of ticked boxes. This is particularly true of accidents which are the product of a complex causal chain. To some extent all coding systems will involve a degree of forced-choice or shoe-horning operations. However the difficulty of this task was underestimated, and this was responsible for a smaller sample of accidents being coded than originally intended in this initial exercise.

5.2 Comments specific to the coding systems

Feggetter's classification was considered to be comprehensive, giving good coverage across the various subsystems. The provision of a label for habit was particularly appropriate in stressing the importance of past experience in shaping behaviour. This made it simple both to acknowledge the number of accidents where task demands were underestimated or poorly planned because they were merely routine, and to note occasions where actions were performed out of habit but where it was inappropriate to the situation. On the downside, the vagueness of some of the terms (eg action) led to coding difficulties. This could lead to some very idiosyncratic coding.

Chappelow's classification is also a blend of behaviourally descriptive and psychological terms. It was particularly easy to implement because its hierarchical nature permits levels of attribution. Furthermore, it is capable of implicating both the aircrew and the system in which they operate. It could benefit from the addition of some headings, (e.g mis- handling, inappropriate technique) and although devised to cover aircrew probably be extended to cover the servicing errors of workshop personnel. These however would be minor modifications.

Reason's GEMS framework is a compelling categorisation of the types of error committed and the cognitive performance with which it is associated. Not only that but it treats errors as a 'normal' by-product of cognitive functioning. Where it was successful it greatly assisted understanding. However it was not easy to employ as a classification scheme, at least partly because the reductionism required in the encoding operations seemed to do little justice to the richness of the details listed in the investigations. For instance some actions were very difficult to code because they appeared to be composites of several categories. There were also grey areas when it was difficult to choose between one category and another. Disentangling accidents with complicated temporal and causal pathways was particularly difficult. Also a very large number of different pre-conditions can give rise to slips and lapses (a many-to-one mapping). The knowledge that a great many accidents are down to skill-based errors is too general to indicate specific areas for remedial action.

This brief examination of Reason's approach does not do justice to his work. For instance he has been at pains for some considerable time to implicate management and organisational aspects in the preparation of fertile ground for accidents i.e. accidents waiting for some 'trigger' mechanism. However even he has acknowledged that his 'latent pathogens' metaphor, despite having "a number of attractive features", is still "far from being a workable theory" because of its vagueness (Ref 3, p 198). We must therefore await its development before the structure can be considered complete. Until that is achieved, a simple listing of enabling circumstances such as that offered by Chappelow may be more practicable.

6. CONCLUSIONS

One limitation of the exercise is the relatively small database of accidents used for evaluation to date. Yet another limitation is the lack of adequate control data, or even the knowledge of what might constitute such controls. Despite these shortcomings, the exercise has yielded a number of common category groupings and in doing so it has also indicated areas where remedial action can be applied.

Although all three taxonomies employed in this study proved useful in classifying the data, the one which was both easier to employ and the most practical in terms of imposing structure on the investigations was that devised by Chappelow.

Aviation represents a dangerous environment. It might be argued that the elimination of errors is not possible. Consultation of Figure 1 might even reinforce this view by suggesting that the asymptote has been reached and that no further improvement is possible. However the categories of error appear to change subtly over time. That fact, and the precise identification of the most current trends as attempted here (eg training deficiencies, changes in crew composition) argues strongly against such a negative view.

Future work will require to continue this exercise for larger samples to ensure that the relatively small number accomplished here has not biased the results unduly. It may also be necessary to test a sample of accidents and preferred classification schemes against a panel of judges to assess inter-rater reliability. Lastly, once there is more general agreement about the scheme(s) to employ and the precise information which should be collected from each investigation to satisfy this need, then larger trans-service and transnational databases might be feasible.

ACKNOWLEDGEMENTS

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ANNEX A. The Three Classification Schemes Employed

COGNITIVE SYSTEM	SITUATIONAL SYSTEM
Human Info Processing	Physical
Sensory	Physical stress
Perception	Physical condition
Attention	Nutrition
Memory	Drugs
Decision	Smoking
Action	Alcohol
Monitoring	Fatigue
Feedback	Sleep loss
Visual Illusions	
False Hypothesis	Environmental Stress
Habits	Attitude
Motivation	Speed and motion
Training	Visual
Personality	Glare
Fear	Disorientation
	Temperature
	Lighting
SOCIAL SYSTEM	Noise
Social pressure	Vibration
Role	
Life stress	Ergonomic Aspects
	Controls
	Displays
	Seating
	Presentation of info
	Emergencies

after Feggetter (1982)

AIRCREW FACTORS	SYSTEM FACTORS	MODES OF FAILURE
Alcohol	A/C handling	Cognitive fail-wrong
Disregard for rules	Erg - Displays	Cognitive fail-
Excess of zeal	Errors in Auto	omission
Fatigue	system	Disorientation
Hypoglycaemia	Noise	Distraction
Inexperience	Comms	'Giant hand'
Joie de Vol	Op. pressure	Inapprop. decision
Lack of airmanship	Time pressure	Inapprop. model
Lack of talent	Training	Overarousal
Life stress	Briefing	Slow response
Low morale	Admin	Stress
Personality	Physiol. stress	Unawareness
QFI/QFI	High workload	Vis. illusion
Sensory limits	Under fire	
Social factors		
Crew Co-ord		
Underarousal		

after Chappelow (1989)

SKILL-BASED	RULE-BASED	KNOWLEDGE-BASED
Inattention	Misapplic. good	Selectivity
Over attention	rules	Workspace Limitations
	Applic. bad rules	Out of sight and mind
		Confirmation Bias
		Over confidence
		Biased review
		Illusory correlation
		Halo effects
		Probs with causality
		Probs with
		complexity

After Reason (1990)

PREDICTION OF SUCCESS FROM TRAINING

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1. SUMMARY

Any training system contains information on the past and current performance of its students. However such systems may also hold predictors capable of estimating the potential of a student.

Failures that occur late during a course result in wasted costs, time and places, and also student career discontent. Therefore identifying the earliest indicators of failure is of primary importance to the operation of an efficient system.

Research directed at uncovering these involves the identification of relevant behaviours; classification of the students' behaviours in real life situations; coding the classifications to form data points; and the application of analytic techniques to produce predictive models of behaviour.

The major emphasis of this paper is to describe attempts to define statistically derived criteria for success and failure in an existing flying training system.

It is argued that the introduction of more objective techniques such as those described here may not only make the training system more efficient but may also reduce flight safety risks.

2. INTRODUCTION

With respect to flight safety and accident prevention, changes in legislation arise as a result of individual accidents or groups of incidents. The method follows a lessons learned approach and therefore relies heavily on a 'post hoc' rationalisation of the relationship of causal factors.

In this field, ethical and financial problems prevent the adoption of an experimental approach in establishing causal relationships between activity and consequence. It is therefore vital to establish a method that is non-interventionist yet does not wait for the, thankfully, limited number of accidents to occur. From the possible set of non-intrusive investigative techniques one appropriate method is to perform an applied psychological assessment of aspects of an entire system and then extract early occurrences of behaviours deemed to be inappropriate. Accident analysis may only reveal the linking of a particular subset of behaviours that correspond to each accident: trends can be detected, but only after large sample sizes are examined. These are not always available. A systems approach will allow a larger set of error categorisation to be constructed. Granted it may elucidate more categories of potential accident behaviour than are represented by an accident analysis, but with an accident only being the end product of a particular set of factors, each category has potential to be part of any accident. Rasmussen describes errors as instances of man-machine mismatches caused by variability on the part of the system or man.

"The interaction can be seen as a complex, multidimensional demand/resource fit. To discuss the misfits and evaluate means for improvement, it is more important to find the nature or dimensions of the misfits than to identify their causes. In other words, it is necessary to find what went wrong rather than why, i.e. to identify potential conflicts, rather than their predecessors in the course of events."

(Rasmussen 1987 p25)

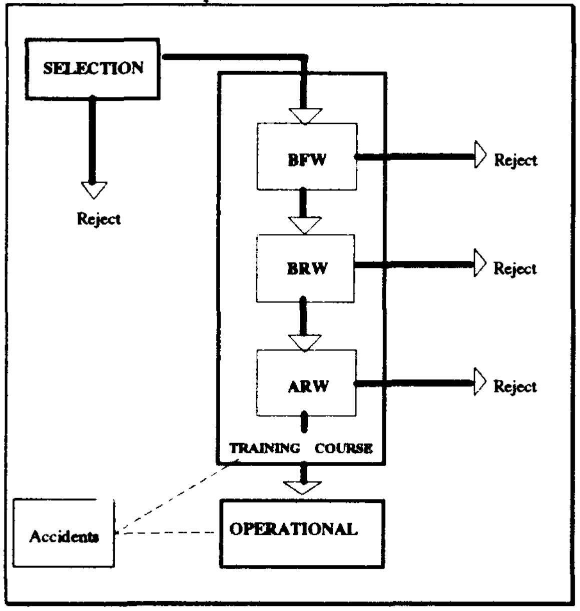
Any organisation will necessarily contain vast amounts of information on both individual and group performances, some of which will be explicit and some implicit. This information is of varying utility from the accident prevention viewpoint. Investigation, however, can be focused on areas of performance weakness identified by subject matter experts operating within the system.

This paper presents some methodological considerations and findings from one of the components of a large scale investigative analysis of helicopter pilot selection, training, operations, and accidents. (Ref 2.)

2.1. DESCRIPTION OF THE SYSTEM UNDER STUDY

Figure 1 depicts a schematised outline of the stages of development of a UK army helicopter pilot from selection to on-line operational roles.

Figure 1. The Stages of Development of an Army Helicopter Pilot.



Once a candidate has been awarded a place on an Army Pilots' Course (APC) the student will go through a three stage training course lasting nine months. The first stage of the APC is on fixed wing Chipmunk aircraft and covers 30 hours basic flying instruction (Basic Fixed Wing - BFW). Next is the first of two rotary wing stages consisting of 50 hours elementary flying on Gazelles (Basic Rotary Wing - BRW). The third stage covers 70 hours advanced flying and tactical awareness training where the student is introduced to the applied skills required for operational flying (Advanced Rotary Wing - ARW). At the end of the course the student will graduate as a pilot and will be posted to an operational unit as a second pilot.

2.2. STUDENT PILOT ASSESSMENT SYSTEM

While under instruction a student is rated during each training sortie on a series of 21 'Basic Abilities' (BAs) listed in Table 1. For each of the Basic Abilities a student will be awarded one of four marks - blue for above average performance, green for average, brown for below average performance and red for a failure.

For this investigation red and brown marks were taken as 'error ratings'. These same 21 BAs are used throughout the three training phases. An instructor or course manager can assess a student's progress by inspecting the sortie summary sheets visually. The numbers and locations of the different colour codes give the instructor indications of performance trends and consistencies in the student.

Table 1. List of Basic Abilities (BAs).

1. LOOKOUT	11. ACCURACY
2. RADIO/TELEPHONE	12. CAPTAINCY
3. DIVISION OF ATTENTION	13. CHECKS
4. ATTITUDE	14. PLANNING
5. FLEXIBILITY	15. BRIEFING
6. STABILITY	16. CREW COOPERATION
7. ANTICIPATION	17. COCKPIT MANAGEMENT
8. RECALL	18. AWARENESS
9. RULE FOLLOWING	19. VISUALISATION
10. OBSERVATION OF AIRCRAFT LIMITATIONS	20. COORDINATION
	21. CONTROL ACTION

Although not mutually exclusive in nature, the BAs do fall into four rough categories. These correspond to psychomotor, cognitive, personality and procedural and are listed below:

PSYCHOMOTOR	11 - Accuracy 20 - Coordination 21 - Control Action
COGNITIVE	3 - Division of Attention 7 - Anticipation 8 - Recall 18 - Awareness 19 - Visualisation
PERSONALITY	4 - Attitude 5 - Flexibility 6 - Stability 12 - Captaincy 16 - Crew Cooperation
PROCEDURAL	1 - Lookout 2 - R/T 9 - Rule Following 10 - Obs. of A/C Limits 13 - Checks 14 - Planning 15 - Briefing 17 - Cockpit Management

However, despite there being a standardised format for rating students, there is no measure of how a particular student compares with other students, or how the student is performing relative to an 'average student'.

In order to compare two students, or one student to the norm , arguably it would be necessary to adopt a form of assessment which is more rigorous than visual inspection.

3. METHOD

3.1. QUANTIFICATION OF ASSESSMENTS

A sample of 184 student flying training folders was examined for this study - 100 pass students and 84 students who failed the course.

Conversion of the colour codings into a numeric system allows the computation of a common denominator by which student records all can be compared. (Fail students are withdrawn from a phase prior to completion therefore will not have completed the same number of sorties as the student who completes the entire phase; therefore a similar unit of measurement is needed to express the levels of marks awarded.) The number of red and brown marks awarded, expressed as a percentage of total grades awarded per student per phase, were used as data points for constructing the data set.

3.2. PROFILE PRODUCTION

These percentages per BA per student per training phase can be used to produce an 'Error Rating Profile' (ERP). An ERP can be produced for an individual student, and also compiled into an averaged profile for an entire set of students. The closeness of fit of an individual student to that of a group of students can be now be represented graphically by overlaying the profile of the student with the profile of the average student.

The data from the training records of previous students who passed or failed the training course were compiled and averaged to produce an ERP for each category. Any current student can then be compared with these two reference ERPs to give an indication of relative performance to each of the pass and fail groups.

4. RESULTS

Figure 2 shows the ERPs for the three phases of training. It can be seen that the three profiles are similar in form and magnitude. However there are also some subtle differences in some of the types of errors made which relate to the specific phases of training. For instance the Advanced Rotary Wing (ARW) students have a tendency to make errors on the more cognitive BAs (e.g. Awareness, Division of Attention and Anticipation) while the Basic Fixed and Basic Rotary Wing students make errors on the psychomotor aspects of flying - i.e. those involved in controlling the aircraft (e.g. Accuracy, Coordination and Control Action).

Figures 3, 4 and 5 show the three phases of training with the sample separated into average pass and fail students. These figures clearly demonstrate that each phase has different profiles for the pass and fail groups; the profiles being both different in form and magnitude.

Figures 6 and 7 show profiles for the BFW and BRW training phases. From these it is clear that students who fail the course at a later stage exhibit a more exaggerated ERP during these early phases than those who go on to pass the course. However, their ERP is not as extreme as those who fail during the early phases. By offering early indications of course results, the ERPs appear to be capable of discriminating between successful and unsuccessful students.

4.1. STATISTICAL ANALYSIS

To test the validity of discriminating by ERP matching it is necessary to ensure that the pass and fail ERPs are in fact independent. Analysis of variance tests showed that the three phases have different ERPs (PHASE: $F=35.761$ df=2,8499 $p<0.001$ and BA: $F=65.847$ df=20,8499 $p<0.001$) but more importantly, each phase has an ERP for pass students that is different from the fail students. Table 2 summarises these results.

The significant ANOVAs show that there are differences of form and magnitude between the pass/fail groups with respect to the ERPs.

Table 2. Two way ANOVAs of Pass/Fail by Basic Ability for each APC phase

BFW:			
PASS/FAIL	F=763.459	df=1,3081	p<0.001
BA	F=16.075	df=20,3081	p<0.001
PASS/FAIL x BA	F=9.239	df=20,3081	p<0.001
BRW:			
PASS/FAIL	F=1491.07	df=1,2814	p<0.001
BA	F=47.126	df=20,2814	p<0.001
PASS/FAIL x BA	F=16.771	df=20,2841	p<0.001
ARW:			
PASS/FAIL	F=1032.58	df=1,2541	p<0.001
BA	F=64.529	df=20,2541	p<0.001
PASS/FAIL x BA	F=13.045	df=20,2541	p<0.001

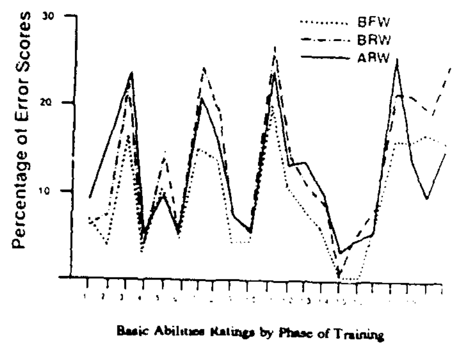


FIGURE 2.

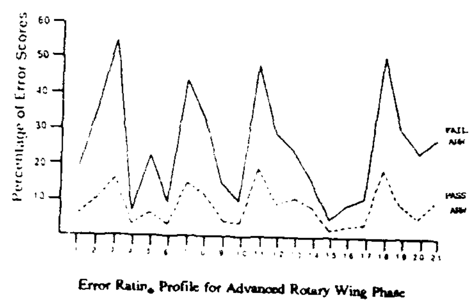


FIGURE 5.

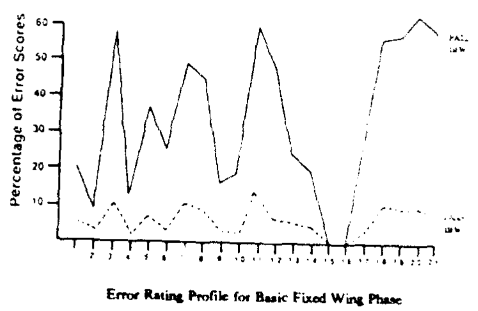


FIGURE 3.

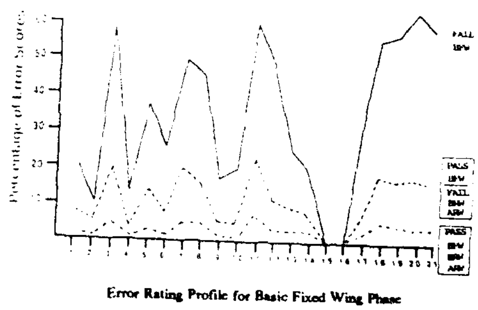


FIGURE 6.

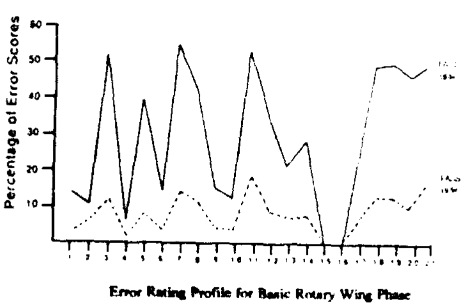


FIGURE 4.

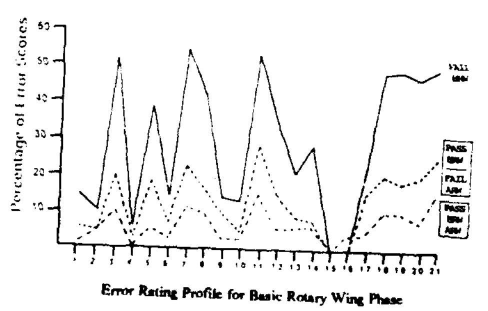


FIGURE 7.

4.2. MULTIVARIATE ANALYSIS

To find out just how the groups differ with respect to the ERPs, the relationship between the BAs and pass/fail criteria was examined more rigorously for each phase. Discriminant Function Analysis (DFA) is a technique for establishing which variables are useful predictors for the statistical differentiation of groups of students. A model (predictive equation) was constructed which assigns probabilities to group membership according to scores on important predictive Basic Abilities. Therefore, as a student progresses through the training course it is possible to produce the probabilities of the student being in the pass and the fail groups. As this can be computed at various critical stages, such as fortnightly progress reviews and handling tests, it would give instructors and course managers early indications of eventual group membership.

Tables 3 to 5 plot the classification results from the three phases of the APC. The levels of Type I and II errors can be seen to be low, while correct acceptance and rejection levels are high, thereby giving indications of a highly predictive model. Only half of the set of student records was used in constructing the models. Following conventional procedures with such exercises, the remaining half was used for internal validation to test the predictive robustness. As can be seen, the classification rates never drop below 80% in the validation groups.

Table 3. BASIC FIXED WING - CLASSIFICATION TABLES FOR MODEL BUILDING AND VALIDATION GROUPS

ACTUAL GROUP MEMBERSHIP	PREDICTED GROUP MEMBERSHIP: FAIL	PASS
FAIL	8 (100%)	0 (0%)
PASS	1 (2%)	71 (98%)

MODEL BUILDING GROUP

Test sample n=80
% of cases correctly classified = 99

ACTUAL GROUP MEMBERSHIP	PREDICTED GROUP MEMBERSHIP: FAIL	PASS
FAIL	6 (86%)	1 (14%)
PASS	6 (9%)	64 (91%)

VALIDATION GROUP

Test sample n=77
% of cases correctly classified = 91

Table 4. BASIC ROTARY WING - CLASSIFICATION TABLES FOR MODEL BUILDING AND VALIDATION GROUPS

ACTUAL GROUP MEMBERSHIP	PREDICTED GROUP MEMBERSHIP: FAIL	PASS
FAIL	13 (93%)	1 (7%)
PASS	1 (2%)	56 (98%)

MODEL BUILDING GROUP

Test sample n=71
% of cases correctly classified = 97

ACTUAL GROUP MEMBERSHIP	PREDICTED GROUP MEMBERSHIP: FAIL	PASS
FAIL	16 (94%)	1 (6%)
PASS	9 (15%)	51 (85%)

VALIDATION GROUP

Test sample n=77
% of cases correctly classified = 87

Table 5. ADVANCED ROTARY WING - CLASSIFICATION TABLES FOR MODEL BUILDING AND VALIDATION GROUPS

MODEL BUILDING GROUP

ACTUAL GROUP MEMBERSHIP	PREDICTED GROUP MEMBERSHIP: FAIL	PREDICTED GROUP MEMBERSHIP: PASS
FAIL	11 (100%)	0 (0%)
PASS	4 (8%)	46 (92%)

Test sample n=61
% of cases correctly classified = 93

VALIDATION GROUP

ACTUAL GROUP MEMBERSHIP	PREDICTED GROUP MEMBERSHIP: FAIL	PREDICTED GROUP MEMBERSHIP: PASS
FAIL	9 (75%)	3 (25%)
PASS	7 (14%)	43 (86%)

Test sample n=62
% of cases correctly classified = 84

The models that were created using the DFA technique and again highlighted the important differences between the pass and fail students. Table 6 presents these important predictive variables for each of the three phases of training.

It can be seen from the predictive variables that the skills where students are noted to make the most errors are related to the specific phases of training. For example, the ARW students can be differentiated by the mistakes they make on almost all of the BAs, whereas the first two phases of training do not have the same quantity of predictive variables. This gives the indication that student performance degrades in a global fashion under the high workload advanced training but specific qualities degrade under basic training.

Table 6. Predictive variables for each APC phase.

BFW	PSYCHOMOTOR	Control Action Coordination Accuracy
	COGNITIVE	Division of Attention Anticipation Visualisation
	PERSONALITY	Stability Flexibility Attitude
	PROCEDURAL	R/T
BRW	PSYCHOMOTOR	Coordination
	COGNITIVE	Recall Awareness
	PERSONALITY	Attitude Flexibility
ARW	PSYCHOMOTOR	Accuracy Control Action Coordination
	COGNITIVE	Division of Attention Anticipation Awareness
	PERSONALITY	Captaincy Attitude Flexibility
	PROCEDURAL	Lookout R/T Rule Following Obs. of A/C Limits Planning Cockpit Management

5. DISCUSSION

5.1 SUMMARY OF APPROACHES

The consequences of each outcome decision can be far reaching. In this case a Type I error (accepting a false hypothesis) would mean pushing a student through the course who would otherwise have failed. Such a student would be a flight safety risk when the student goes on to an operational unit. A Type II error (rejecting a true hypothesis) would mean failing a student who would otherwise have passed the course, thereby constituting a waste of resources and risking career discontent for the student. When assigning a student to a particular group by any of the methods described in this paper, the respective consequences of the two error types will weigh heavily on the instructor's mind. The more information there is to hand, the less likely the instructor is to make an erroneous decision.

By overlaying the profiles it is possible to assess subjectively the similarity of a student's performance to that of the average pass or fail student. Alternatively we can mathematically predict the similarity of each of the groups. This technique, therefore, establishes a testable model of behaviour assessment - a 'mathematical' method of proactive monitoring. This can be used in conjunction with the psychological technique of profile matching, the traditional method of visually inspecting the sortie summary sheets, and the subjective impression of the instructor.

It is proposed that the eventual role for these models and techniques lies in aiding instructors and course organisers in their outcome decision judgements. The current state of flux in curricula and manning requirements implies that each of the techniques described could only offer subsidiary information in management decisions on students. However despite this limitation, it does offer a more objective assessment of students employing the same criteria that instructors use, and can also act as definitive references for new instructors.

5.2. VALIDATION EXERCISES

External validation exercises are planned to test fully the efficiency of these models and techniques. The three main areas being researched are:

1. Investigation of why certain basic abilities are predictive in each phase.

2. Prediction of outcome for students who are training using the various proposed techniques. This will take a longitudinal perspective on validation as modifications can be made to the models to reflect changes to the training system.

3. Concurrent feedback on on-line predictions from instructors in an attempt to fine-tune the models. By offering extra information not included in the written assessment system it may be possible to define more fully the important predictors that are being used to make the outcome decision.

It is envisaged that the validation exercises will prove the final utility of the approach from subjective and objective standpoints. Statistical purity and acceptance of this additional source of information by the instructors will be the aims of the validation exercises.

5.3. LIMITATIONS OF THIS APPROACH

Attempts to produce a robust probabilistic model of this kind using this type of data will be subject to methodological shortfalls. These limitations have to be borne in mind when trying to assess the TRUE potential of the different methods in predicting course outcome. A number of these are outlined below.

5.3.1. Subjectivity

The assessment of pilots throughout all branches of aviation contains a largely subjective component. Flying time and instructional charges are expensive. Great emphasis, therefore, is placed on the experience of the instructor. Even when the results of this subjectively operated 'objective' system are subjected to analysis we cannot remove these individual differences. The exact meanings of these Basic Abilities and the rating scheme may be being used very idiosyncratically. However, when the data set was compiled using the instructors as subjects for profile production (i.e. a profile of red and brown rating percentages per BA for each instructor across all of his students) very encouraging results emerged. The ERPs indicated how similar the instructors were in their usage of these BAs. Future research is aimed at clarifying some of these issues both for a better understanding of the current assessment system and also as a means of carrying out the necessary groundwork for any new assessment system.

5.3.2. Circularity

The same instructors grade candidates, train and mark them as students and also contribute towards the final outcome decision of the course. There are procedures for attempting to standardise the instructors' working routines, but by the very nature of flying, there are many unaccountable intervening variables.

An instructor may only be examining certain sets of BAs in each phase, therefore the predictive/high peaked ERP BAs may be limited to that specific phase.

5.3.3. Efficacy

The 21 Basic Abilities may not be the best measures for producing pass/fail criteria. Principle Component Analysis results show that there may be fewer critical variables than the scheme suggests (Ref. 2). A more succinct assessment system may be operating in the minds of the instructors. The outcome of the course may be a product of other factors that are unrelated to the assessment system as it appears in the analysis. As yet undefined qualities may be being used to appraise students. These would bias the outcome criteria away from the Basic Abilities and cause an artificial lowering of the correlations of the Basic Abilities with the outcome performance.

5.3.4. Outcome equivalence

Unequal opportunities are given to some students within a course as review action and re-coursing are available to the less able students. (Students who demonstrate weakness at particular skills can be given extra tuition to bring performance to the same level as the other students on the course. This is called review action.) Again this lowers the correlation coefficients between assessments and outcome.

Changes to the syllabus occur from time to time as the requirements change due to new equipment and procedures being introduced. These have to be reflected in the training course, and hence also have undesirable effects on the consistency of the outcome decisions.

5.4. COUNTERMEASURES

There are several methods by which the effects of the above limitations can be reduced. The major ones are listed below:

(i) Checking the statistical validity of models by examining the amounts of variance accounted for.

(ii) Employing large sample sizes from a short stable training period.

(iii) Conducting internal validation and checking.

(iv) Investigating the assessment system with respect to understanding how it works and what relationship these results have to other findings.

(v) Instigating a rigorous set of trials and follow up studies.

Work is currently being undertaken on the assessment system prior to a large scale validation.

6. CONCLUSION

The assessment system operating during the training of UK Army Helicopter pilots has a large subjective component. There are important consequences of making an erroneous outcome decision. The more information that an assessor or course organiser has when making that outcome decision the less chance there is of making the wrong decision.

This paper has presented some standardised pictorial and numeric aides for the course organiser based on the instructors' own perceptions of the rating system and existing course data. The results obtained thus far are encouraging, and it has further exemplified the ability of statistical techniques to be employed in reducing flight safety risks.

7. ACKNOWLEDGEMENTS

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MEDICAL EVALUATION OF SPATIAL DISORIENTATION MISHAPS

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SUMMARY

Spatial Disorientation (SD) is a leading human-factors cause of class A mishaps in all branches of the U.S. Armed Forces. Recently, several pilots who performed well under most flight conditions were referred to the Naval Aerospace Medical Research Laboratory (NAMRL) because of inability to fly under specific conditions conducive to SD. Most had been neurologically classified as normal using the presently available clinical tests. The pilots were then referred to NAMRL for assessment of vestibular function. Some of these pilots demonstrated perceptual anomalies in attitude perception that rendered them unable to fly safely under select combinations of acceleration and visual presentations. Although U.S. Navy pilot applicants are thoroughly assessed to meet visual and auditory standards, there are no specific screening tests for vestibular function. Thus, it is possible for members of the pilot community to possess reactions that under certain conditions will render them particularly susceptible to SD. In response to requests from clinicians, we have initiated the development of a Pensacola Vestibular Test Battery (PVTB) to assess aircrew referrals. The PVTB is being used to build a normative and pathological data base that will be incorporated into mathematical models that will inform the clinicians of the perceptual consequences of vestibular anomalies in the flight environment. The same computer-based models will be useful for aircraft design, pilot selection, and mishap investigation.

INTRODUCTION

When aircraft mishaps are categorized by causation factors, the largest single factor is consistently pilot error. Despite a declining overall accident rate, the proportion of pilot error accidents indicates little or no improvement. The U.S. Air Force has indicated that the most significant human-factors problem facing the Tactical Air Command is Spatial Disorientation (1). Statistics from the U.S. Navy indicate SD and crew coordination are the most significant human factors contributing to class A mishaps. Annually the three branches of the U.S. Department of Defense lose aircraft costing in excess of 300 million dollars and 20 to 30 lives (2,3,4). Of the 15 Navy aircraft lost to noncombatant action in the recent Iraq conflit, 7 were SD mishaps (5). During the Falkland conflict, 5 of the 6 helicopter losses experienced by the British were due to SD (3). Mission success is frequently compromised by SD (e.g., the Iran hostage rescue team was forced to turn back due to a SD mishap at the Desert One rendezvous site (6)). In summary, among human-factors problems that account for the bulk of aircraft mishaps, spatial disorientation is the most significant both in terms of material and personnel lost as well as mission degradation.

The opportunities for SD mishaps are constantly increasing due to more frequent night operations, requirements for all weather flying, increased low level or nap of the earth flight, use of night vision goggles (NVG) which decreases peripheral vision, improved agility of aircraft, and more demanding pilot workload including fatigue-producing sustained operations--all factors that are conducive to spatial disorientation. As individual aircraft costs escalate, the military, especially in times of constrained budgets, cannot afford the continued loss of what in many cases are becoming nonrenewable resources.

Spatial disorientation mishaps have occurred since terrestrial man, who evolved in a two-dimensional environment, entered the dynamic three-dimensional aeronautical environment. As long as the first aviators could maintain visual reference with respect to the ground or horizon, orientation did not pose a significant problem. However, "cloud flying" and other phases or forms of flight in reduced visibility claimed early aviators as victims with an alarming frequency. The incidence of SD dramatically declined when Sperry introduced the gyro-stabilized artificial horizon. Why is it that since Sperry's time, there have been no further landmark developments by the human-factors engineers in introducing displays or instrumentation to solve orientation problems? It may be that spatial orientation, which even on the ground involves a simultaneous integration of information from multiple sensory systems, poses an even more complex problem in the aerial environment such that human-factors solutions must come from more than one sensory system.

Terrestrially, each of the sensory systems involved in maintaining orientation (vestibular, kinesthetic/tactile, vision, and to a small extent auditory) provide independent, continuous, complementary, and reliable sources of information that are integrated in the central nervous system to formulate an appropriate response. However, in the aeronautical environment the proprioceptive (vestibular and kinesthetic) and tactile sensations no longer provide accurate information concerning the magnitude or direction of the gravity vector. This is in part due to the continuous variations in magnitude and direction of the resultant gravitoinertial force vector and in part due to the unusual nature of rotational movement to which the pilot is exposed. The only reliable source of information remaining is that obtained through the visual system. Thus, in flight, the central nervous system has the added responsibility of determining what sensor information is valid. The typical spatial disorientation mishap occurs when the visual orientation system is compromised (e.g., temporary distractions, increased workload, VFR/IFR transitions, or reduced visibility) and the central nervous system must then compute orientation with the only information at its disposal (i.e., vestibular and somatosensory), which happens to be incorrect.

When disorientation occurs on the ground, we can usually attribute the cause to some underlying pathology. In the air, SD is a normal occurrence for normal pilots and is to be expected even in the absence of any pathology. This paper will address techniques to identify a class of pilots in whom pathological vestibular processes exist that predispose them to experiencing SD.

Unlike other sensory end organs, the vestibular sensory apparatus has not proven amenable to accurate measurement by simple or complex tests. With the visual and auditory systems, the ease with which one can accurately and quantitatively measure such parameters as acuity, accommodative ability, color discrimination, etc., has permitted the compilation of extensive normative data with which to compare individuals of any age or sex. The military and civilian communities have long utilized these data to set minimum qualifications for selection into various communities (e.g., pilots, submariners) or to determine fitness for continued duty. The nonavailability of normative data and simple tests for the vestibular system and its interaction with other sensory systems has resulted in the acceptance and training of pilot candidates who are later unable to complete the curriculum due to vestibular deficiencies.

The primary reason that vestibular tests are inaccurate and/or inadequate is that they measure the vestibular end organ indirectly. That is, they measure the effect of the vestibular sensory system on a motor response (e.g., eye movement in response to a vestibular stimulus, or balance in response to perturbation of movement or sensory deprivation). Although the vestibular nuclei are the primary recipients of the vestibular end organ signals, they also receive and coordinate position and motion information from a variety of sources (visual, somatosensory, auditory, and corollary motor commands) to effect an appropriate response or reflex such as postural control or visual stability, or an undesirable effect such as motion sickness.

These motor responses are subject to modulation by several central nervous system centers. Specific tests to measure vestibular function and its interactions must maintain precise control of these other input systems. Although extraneous visual and auditory input may be eliminated in an attempt to isolate the effect of a vestibular stimulus, touch and the nonvestibular proprioceptive senses (muscle, tendon and joint) cannot be eliminated. In the real world, we must assess the interaction of one or more systems with known vestibular stimuli, and within the vestibular system, we must assess not only canal function and otolith function, but also the several ways canal and otolith systems interact to alter our response to motion.

Orientation and equilibrium information are received at the parietal cortex (S II or somatosensory area II), which by virtue of its anatomical connections is the cortical area most likely responsible for kinesthesia and perceptual orientation in space. Area S II, in addition to being the primary cortical area to receive vestibular afferent information (7,8), also receives highly processed visual (9), auditory (10), and nonvestibular proprioceptive (11) information as well as corollary discharges (12) from the motor cortex. From the standpoint of the cortical perceptual level, a "simple" vestibular motion stimulus is subject to an even greater number of influences than the brain stem processing centers. By comparison, the "traditional senses" remain relatively uncontaminated by other sensory systems as they ascend via relays to the higher level of the cortex although vestibular information alters visual transmission at early levels. At the reflex and perceptual levels, the effects of vestibular end organ stimulation pose measurement problems due to the multisensory integrative nature of the vestibular system.

Perceptual orientation, kinesthesia and maintenance of posture are absolutely fundamental for survival; natural selection has avoided excessive reliance on any single sense organ by employing multiple redundancies in this information system. A gradual compromise of any one channel will not fully jeopardize the ability to orient if other systems remain intact. An individual can adapt to a gradual loss of vestibular end organ function with no apparent deficit. However, when a second system is compromised, such as closing the eyes in the Romberg test, the individual will be unable to maintain balance. Similarly, a blind man can readily maintain balance or ambulate provided vestibular and other proprioceptive information remain intact. The central integrating role of the vestibular system in orientation is evidenced by the profound incapacitation of the patient suffering an acute vestibular lesion (e.g., viral infection or unilateral labyrinthectomy). Such a patient is unable to stand, walk or maintain stable vision, but in time, the central integrating centers reequilibrate, and equilibrium is restored which demonstrates the adaptive capacity of the central vestibular system. For the purpose of our discussion, the vestibular system includes 1) the labyrinth end-organ, 2) primary afferents to vestibular nuclei (including the vestibulocerebellum), 3) ascending and descending vestibular projections to ocular and spinal musculature, 4) vestibular projections to parietal cortex for spatial perception and 5) efferent projections to the labyrinth end-organ.

The clinical vestibular tests presently available to neurologists are at best, qualitative, highly subjective, and frequently uncomfortable to the patient (e.g., caloric stimulation). During the initial screening of aviators or U.S. military personnel, the only test of vestibular function administered by flight surgeons is the 10-second Romberg (self balance) test, which can be passed by vestibularly compromised subjects who have developed good nonlabyrinthine compensatory mechanisms. Often, aviators and Naval Flight Officers (NFOs) come to our attention late in flight training or after designation who do not have the necessary physiological skills (vestibular in this case) to fly safely.

Most pilots or NFOs are notorious in their attempts to hide or cover-up physically disqualifying defects during the flight physical exam. The deficit, if detected, usually comes to the attention of the flight surgeon when the flight instructor observes a training problem and refers the student or aviator to the flight surgeon. Most frequently, vestibular deficits present as the inability to maintain controlled flight in actual or simulated instrument meteorological conditions when the pilot is deprived of outside visual references. Over the past 3 years, cooperative efforts by the Naval Aerospace Medical Institute (NAMI) and NAMRL to examine selected aviator medical referrals have led to documentation of a vestibular integrative deficiency responsible for the inability to maintain flight in instrument meteorological conditions.

Selected case histories from our files of pilot referrals will illustrate why the development of a vestibular test battery employing specialized NAMRL equipment is imperative to the proper examination of pilots surviving suspected SD mishaps. In today's climate of preventive medicine we have the opportunity to reduce the incidence of SD mishaps and prevent repeat occurrences when individuals with pathology can be identified.

CASE HISTORIES AND INITIAL OBSERVATIONS

Case 1: A 24-year-old Caucasian male student Naval aviator in advanced jet training, who had above average grades in primary flight training, experienced difficulties maintaining aircraft control during a turbulent check ride in instrument conditions. On further questioning, he admitted to difficulty in reading instruments during turbulence. When he encountered turbulence during earlier training flights, the meteorological conditions were such that he could maintain orientation using outside visual reference. Of significance in his past history was an episode of vertigo, nausea, and vomiting for 3 days at age 13–a probable vestibular neuritis. Although he could perform the standard Romberg test, he was unable to stand in the sharpened Romberg position (tandem heel to toe stance, arms folded on chest, and head extended with eyes closed). The vestibular ocular reflex was absent both horizontally and vertically, which explained his inability to read the instrument panel during turbulence.

Case 1 illustrates that present entrance physicals can fail to detect disqualifying deficiencies in vestibular function. This pathology could have been easily detected with simple and quick clinical tests of vestibular function if included in the screening physical. This advanced student jet pilot in whom the Navy had invested in excess of $800,000 in training over 3 years needed only two more flights to receive his wings and join the fleet. Since moderate turbulence in the absence of outside visual references evoked uncontrolled flight, it would only have been a matter of time before a mishap occurred. It is not known how many fatal spatial disorientation mishap pilots have possessed such pathological traits, especially when screening tests of vestibular function are not routine. Given the minimal cost in time and money to include simple vestibular tests in the original physical exam, it would obviously be cost effective for the military to identify such pilots prior to losing huge sums of money to training failures even if only one pilot is found every 4 years. From the military point of view a mission failure can have even more disastrous results.

Case 2: A 25-year-old Caucasian male, U.S. Army student pilot, was referred for recurrent in-flight disequilibrium experienced while flying under the instrument hood in UH-1 helicopters. When deprived of external visual reference, the patient described continuous right roll and forward pitch sensations of such a compelling nature that he could not maintain control within the prescribed altitude limits required by the Army flight syllabus. The patient had experienced no difficulty in the previous 120 hours of flight training where visual references were present or while in the simulator practicing IMC procedures. All neurological examinations and tests were within normal limits. The pilot candidate was further examined on a variety of motion based devices as follows:

1. The Multiple Station Disorientation Demonstrator (MSDD) is a rotating platform with individual capsules approximately 9 ft from the center of rotation. By changing the orientation of the capsule in yaw while the device is at constant velocity, various conditions of maintained "linear" acceleration or deceleration can be experienced without inducing the confounding effects of Coriolis cross-coupling.

For example, when the capsule is oriented such that the occupant faces radially inboard or outboard, he will experience pitch up or pitch down respectively. A normal subject can report or indicate with a pitch indicator his perceived pitch attitude within a few degrees of the resultant gravitoinertial force vector. At constant velocities in the dark, this student pilot usually perceived correctly the initial stimulus in any given set of acceleration patterns. Subsequent changes of capsule position resulted in perceived pitch changes in the opposite direction to that experienced by our normal pilots. Furthermore, during transitions between positions, the magnitude of his sensations was greater and durations were greater than average by factors of 2 to 5. As expected, the magnitude and duration of his perception errors were reduced in the presence of visual frames of reference.

2. Further tests, including visual vestibular interactions, were carried out onboard the Dynasim, a short-armed centrifuge with a cockpit mounted tangentially (facing the direction of rotation) at the end of an 8 ft arm. A target which rotated with the subject was projected on the wall of the 50 ft diameter room. While rotating and with Z-axis aligned with the resultant gravitoinertial force, the patient gave subjective information on changes in the target position when he moved his head from the cockpit instrument panel to acquire the target 90 deg to his right (16 rpm and 30 deg angle of bank). The time frame of perceived target motion in this patient was longer by a factor of 5 to 10 than our normal pilot candidates. The pilot also reported a rotational oscillation, approximately 1 Hz, of the stationary target approximately 30 s after visual acquisition.

When the patient was slowly decelerated from 16 to 10 rpm, he perceived pitch in the opposite direction to that observed by normal subjects. As on the MSDD, the duration and extent of these false perceptions were reduced by low-level ambient lighting. Once again, the first acceleration was typically perceived correctly as pitch upward.

3. The last testing procedure utilized a *20-ft centrifuge with a ramp* acceleration to 3 G for 1 min followed by a deceleration to 1 G. The patient lay in a chair pivoted to maintain alignment of the resultant force with his anterior-posterior (Gx) axis. At constant velocity when most experimental subjects do not experience pitch motion, the patient experienced continuous feet over head rotation in pitch while also reporting a sensation of being upside down (head to earth). The patient experienced a "posimotion" illusion--that is, he experienced simultaneously a sensation of continuous pitch velocity motion, which was not matched by an appropriate change in pitch position. A paradoxical response similar to this is experienced during centrifuge deceleration and is a reason why many pilots do not like centrifuge training. However, our patient experienced this throughout the 60 s of constant velocity, a phenomenon we have not observed previously in any pilot or student pilot subject. Again on deceleration, his perceptions did not match the norms, which indicates that his vestibular sensations are far outside our normal population.

Case 3: A 34-year-old Caucasian male Naval aviator and recent jet test pilot graduate was referred for new onset of recurrent SD. During an F-14 requalification flight, abnormal pitch perception in actual instrument conditions was precipitated by level deceleration (e.g., configurational changes such as wings brought forward and gear down) resulting in pilot induced oscillation and an inability to maintain altitude control within +/- 500 ft. There was no history of motion or simulator sickness. Four years prior, he developed a moderately severe case of gastroenteritis, microhematuria, and progressive temporal headaches with visual blurring and mild nausea. Work-up including CT scan and lumbar puncture was negative. The headaches, which were attributed to a possible viral syndrome, resolved within 2 months, and the pilot was returned to flight status.

All neurological and neurovestibular exams were normal. Using a darkened pendular centrifuge cab, the patient was exposed to a 3-Gz acceleration profile that in normal subjects elicits strong pitch forward (down) sensations during deceleration. The consistent response in this pilot was pitch backward (up), which was in keeping *with his problem of pilot-induced oscillation in pitch attitude control* in flight. It should be noted that this test pilot did not experience any control problems when flying with adequate outside ground or horizon cues. The aeromedical disposition was to continue him in a flight status but only with a safety pilot present.

As in case 1, had it not been for chance meteorological conditions, this pilot would have continued *flying until either a mishap* occurred or he voluntarily presented himself to medical personnel. The latter rarely occurs given the type-A personality of most military aviators and the rarity with which pilots have drawn attention to conditions that might disqualify them from flying. The student pilot in Case 2 who had above-average flight grades indicated that by "sneaking glances" while under the hood he could reduce or abolish the disturbing illusions and maintain aircraft control sufficiently to complete the curriculum. Had he done so and been involved in a fatal accident (and so many SD mishaps are fatal) the mishap investigation team could have never *recognized the cause of the mishap as being a physiological problem.* The same is true of Cases 1 and 2.

What makes Cases 2 and 3 so unique is that there are no clinically available tests for flight surgeons to identify these deficits. Currently, only with only highly specialized equipment and subspecialists can pilots with these traits be diagnosed.

Case 4: A 41-year-old Caucasian Army instructor pilot, involved in a SD mishap on a low-light NVG flight, erroneously felt his aircraft pitch while flying straight and level over black asphalt. When he "corrected" his perceived pitch, the helicopter impacted the ground. Neurological examination and all tests were normal.

When the pilot was placed on the MSDD and the resultant force vector was adjusted to be 20-deg lateral, a situation in which he should have experienced a 20 deg roll, his perception was in excess of 90 deg roll.

Case 4 represents the first SD mishap survivor with normal clinical findings who presents with abnormal perceptions which predispose to SD mishaps. This mishap could have been averted if the vestibular tests now being developed were available for screening when he entered the military.

In response to frequent requests by NAMI clinicians for vestibular testing, it was obvious the Naval Aerospace Medical Research Laboratory needed a systematic approach to examine pilots referred for SD complaints. The NAMI departments of Internal Medicine, Neurology, ENT, and Psychiatry thoroughly assess each pilot before referring them to NAMRL. Due to interest by the current NAMI clinicians, the Neurology and ENT departments complete the following battery of vestibular tests (13):

Clinical Tests:

Positional Testing - Hallpike maneuver, head hanging, head shaking, Barany chair rotation

Fistula Testing - tragus compression, suction (Hennebert's sign), noise (Tullio's phenomenon), valsalva and swallowing.

Postural Testing - sharpened Romberg, Quix test, past pointing

Gait Testing - Fukada step test, Unterberger step test

Nystagmus Evaluation - type, direction, conjugacy, latency, fatigue/habituation, fixation effects, gaze evoked.

Visual Testing - pursuit, saccades, VOR, VOR suppression

Neurodiagnostic Tests:

Caloric Testing

Visual Testing - EOG calibration, optokinetic nystagmus

Specialized Neurodiagnostic Tests (NAMRL-based):

Off Vertical Rotation - Neurokinetics chair

Platform Testing - Equitest Platform

This initial work-up far exceeds the recently recommended standardized basic vestibular function test battery (14) and exists presently because of the interest of physicians currently in residence. The Navy Research and Development Command in response to requests from NAMI clinicians has approved the development of the Pensacola Vestibular Test Battery (PVTB) to examine aspects of vestibular function utilizing our unique resources and expertise. This action should ensure the presence in the Navy of the testing capabilities needed to prevent SD losses due to vestibular dysfunction in flight. To prioritize the wide variety of tests available at NAMRL, a group of national and international neurootologists and vestibular researchers convenes annually to guide test development. The group discusses approaches to individual cases and will also accept referrals to their own specialized testing facilities. We anticipate accepting selected civilian patient referrals to aid in validation of our tests. Tests will be deleted or added until a well-defined battery is available for delivery to NAMI. NAMI will use these tests to examine referrals from the fleet and monitor rehabilitation of pilots with acute vestibular lesions.

Some procedures will be applicable to low-cost screening of applicants. Three of the above cases appeared to have abnormal perceptual responses to otolith stimuli. A high priority for the aeromedical community is a simple screening test of otolith function. The MSDD is the ideal platform from which to obtain normative data on central processing of otolith information, (e.g., perceptual responses to maintained acceleration and to passive changes in resultant gravitoinertial vector). Recording facilities already in place on the MSDD permit responses to be obtained from up to 10 subjects simultaneously (15). Given that all incoming Navy aircrew receive disorientation training on this device, once the normative data is obtained, the MSDD will be the ideal screening tool to detect abnormal otolith function among aircrew. Aircrew with responses outside normal limits will be given additional, quantitative testing to more accurately assess the level of vestibular function. As part of a validation paradigm, labyrinth-defective and selected clinical patients will be exposed to these gravitoinertial forces to determine the subjective response attributed to the nonvestibular gravitoceptors. Other tests presently being evaluated include Balance Platform testing, Visual Vestibular Interaction Tests, Off Vertical Rotation Test, Ocular Counter Roll and Linear Oscillation.

CONCLUSIONS

Several points may be drawn from the preceding case histories, which were selected as a sample of SD pilot referrals to NAMRL.

1. Pilot referrals do not receive adequate screening of vestibular function despite current availability of clinical tests that can detect disqualifying defects. A simple and available test could have detected the pilot in case 1 and prevented the loss of close to $1 million.

2. The presently available tests of clinical vestibular function are not capable of identifying a group of pilots (e.g., cases 2, 3, and 4) who possess traits that render them highly susceptible to spatial disorientation. At present, specialized acceleration devices and experts familiar with normal responses are required to diagnose this group. For these tests to be useful in screening, large normative and pathological data bases must be constructed in order to establish accurate confidence intervals for selection criteria. Large-scale screening will also establish the incidence of vestibular deficits and indicate the cost effectiveness of the proposed screening program. Cross- sectional and longitudinal studies for each new test in the PVTB as well as for each in the standard test battery are necessary to obtain reliable normative data for various age groups. In contrast to the hearing and vision communities, the vestibular testing community has not identified the normal changes with age.

3. Aeromedical clinicians need to carefully address the pros and cons of adaptive conditioning in overcoming the immediate postural control problems of acute deficits in vestibular function (e.g., case 3). The PVTB should include the capability of assessing progress in the rehabilitation of pilots undergoing such adaptive reconditioning.

4. A strong educational awareness program is required to inform instructor pilots and flight surgeons of the physiological traits that can present as unexpected poor flight performance under instrument conditions (cases 1 - 4). It should be noted that the pilot in case 1 came to our attention only as a result of a perceptive, sensitive instructor pilot who sent the advanced jet student to a flight surgeon who in turn was sufficiently intrigued to refer him to NAMI Neurology. The more typical disposition is a failed flight grade with subsequent attrition from the program. Instructor pilots who in the past have attributed poor instrument grades in otherwise good students to a lack of "the right stuff" and who have attrited students from the flight program might instead consider a referral to the flight surgeon.

Many pilots have strong interests in this topic when given opportunity to discuss it with specialists. If fostered, this interest could serve to prevent SD losses.

5. The specialized tests in the PVTB demonstrate the need for an interdisciplinary approach to testing, which will be most effective when a neurootologist receives support from vestibular scientists as well as specialists in vision, auditory, and psychophysiological research. In contrast to other senses, the vestibular system is better characterized as a sensory motor system interacting strongly with vision, proprioception, and to a lesser degree audition. This later point should represent the approach to be taken by human-factors engineers in developing a better man-machine interface to aid the pilot in maintaining spatial orientation awareness. The current engineering emphasis on development of improved visual displays as a panacea to solving spatial disorientation is not the answer. Engineers should emulate the approach used by all animals in maintaining orientation, namely the coordination and integration by the vestibular system of visual, proprioceptive and auditory information.

6. It should be emphasized that most SD mishaps are the result of a normal response by a normal pilot and that these special conditions are omnipresent in the aeronautical environment. Only through better man-machine interfaces will significant reductions be made in the incidence of SD mishaps. The tests described in this paper can identify a group of pilots who possess traits that do not significantly affect performance on the ground but which render them more susceptible to the ever looming specter of SD in the air.

7. The devastating consequences of SD mishaps justify the expenditures of large research resources to reduce by even a small increment the incidence of SD. Basic research into SD mechanisms when incorporated with the normative data we propose to collect will permit development of models capable of predicting perceptual and sensory motor responses to accelerations in the aeronautical environment. Aircraft manufacturers have requested this information now that aircraft can easily exceed the physiological envelope of the human organism. When there are no survivors from a mishap, investigators will be able to use the models to reconstruct the dynamics of expected spatial orientation perceptual responses in normal individuals in that particular flight condition(s). In addition, clinicians will be able to envision the perceptual consequences of vestibular dysfunction in special conditions of aviation.

RECOMMENDATIONS

1. Aggressively test vestibular function in a) survivors of suspected spatial disorientation mishaps and b) pilots experiencing difficulties with instrument flying.

2. Build a data base of normative and pathological responses to each vestibular test such that limits can be set for use in screening applicants. Determine the performance decrement for each test as a function of age.

3. Develop a program to monitor rehabilitation of aircrew recovering from acute vestibular insults.

4. Screen pilot applicants thoroughly to a) prevent attrition at later stages in the training pipeline and b) reduce incidence of spatial disorientation mishaps.

5. Educate instructor pilots and flight surgeons as to the existence of physiological traits in pilots that can result in an increased susceptibility to spatial disorientation.

6. Improve the man-machine interface by emphasizing the integration of several sensory modalities including proprioceptive and auditory displays.

7. Develop a predictive model of perceptual response to acceleration stimuli that occur in the aeronautical environment. This will help a) mishap investigators understand the dynamics of aircraft mishaps and b) human factors engineers in designing an improved sensory interface to reduce spatial disorientation mishaps.

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THE NEXT GENERATION FEMALE IN COCKPIT - DO WE NEED A NEW APPROACH TO COCKPIT RESOURCE MANAGEMENT (CRM) ?

by

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Several aviation accidents are caused by inadequate or misinterpreted communication within the crew or between cockpit and ATC. Wheale (1983) revealed that of 250 airline pilots, 40% of the first officers admitted that they once or several times had failed to communicate their doubts about the operation of the aircraft. Proper exchange of information on the flight deck may be due to cultural differences (Foushee 1982). Hofstede defines culture as a value system that affects our priorities and the decisions we make. This may indicate that cultural differences could cause a desire to avoid conflict and questioning of the authority of the captain. The spoken language has much redundancy and is therefore versatile. This redundancy could also cause problems of exact understanding. What is registred by the listener is based on previous experience, learning and expectation, so there is a risk of false hypothesis emerging which alledgedly has been a source for several accidents.

The problem of ambigous communication in aviation has existed ever since the first multi crew cockpit and the emerging of the first ATC, and has received much attention within human factor research. However, most of this research has been performed in the single sex cockpit and has not taken into consideration the new aspect of the situation: female aviators entering the scene.
One should be aware that cultural differences do not only exist between countries, but also between the two sexes. The differences include a value system which affects our priorities and the decisions we make. We have to accept that a different value system between subgroups do affect both our perception and the decision making styles. With the introduction of the two sex cockpit the instructors should acknowledge these differences and try to create teaching situations which create the desired outcome from the two different groups of pilot trainees. If the differences are ignored at the start of the learning period one may risk getting lost at an early stage of the process.

Most studies that have examined the effect of pilot training have focused on very limited periodes of time, primarily on the ab initio training. Helmreich, Sawin and Carsrud (1986) conclude that performance shortly after the training period is less sensitive to personality traits than performance after a long experience in the cockpit. During training most people are motivated to do as well as possible. Over time when the profession becomes routine, personality charachteristics are the most important predictors of performance.

The present pilot training put more highlight on personality attitudes that favour crew coordination in addition to technical expertise than earlier days of pilot training. This may imply that cultural differences more easily will emerge and have to be taken into training considerations instead of more or less ignoring them as was possible when the operational performance proficiency was all that really mattered for the professional pilot. With more females entering pilot training one should accept that the two sexes emerge from different subcultures and consider the possibility that different training strategies, especially within crew resource management training may work more effectively than it has up till now.

Aviation Week and Space Technology (1992) reveals than overall the world there are 2.000 women transport crewmembers. This means an increase of more than 300% since 1980. In the U.S. females represent about 3% of all commercial pilots. Within the armed Forces females have also started to participate in nontraditional combat operations. This is also the picture in Norway where the first female fighter pilot will complete her training in 1992.
So far pilot selection criteria and training programs have been and are identical for both sexes in the RNoAF. Only few women have entered the aircraft cockpits, which may still rightly be called "male territory". The few women in the Air Force have adjusted well in their jobs. This may be explained by that the girls who have applied for pilot training have been extremely motivated and competent. Another factor may be that these women have realized that they have had to adjust to the male territory with "male rules and terms". However, there is a possibility that the next generation of female aviators may differ from the pioneer generation in that they no longer will accept the existing rules. We foresee that future female aviators will demand adjustments fo the current rules to meet new requirements since the next generation female pilots will be provided with successful role models that their elders lacked, and thus make the cockpit a "mixed double" working place where both sexes have to adjust.

Several studies have revealed that men and women among other things communicate differently. Where men often use "matter of fact" messages, women are known to send "less direct" messages. The fact that there are already too many misinterpretations within "male only" air crew has focused on the hazards relating to communication procedures, training and standards. Rather than ignore the sex differences or hoping they will disappear, it is time to accept the differences of the sexes and provide information on how the differences were established and why, and make this knowledge part of the compulsory pilot education and later part of the crew resource management training.

With crew resource mangement training being part of the licensing requirements this subject should among other topics focus on the communicational differences between male and female pilots. This focusing should not underline the differences in a negative way, but point to them in such a way that one becomes aware of them and accepts them.

In a rough inflight situation with unstable wind conditions a female captain asked her male copilot who was pilot flying if he "was happy", implying probably if she should take over the controls. The copilot answered that he was O.K. and continued the decent which ended with a crash killing three people. The outcome of this flight might have been the same if the captain had taken over the controls, but the setting of the cockpit gave inputs to a train on questions:
Would a male captain have phrased himself differently in an identical situation?
Would the phraseology have been the same with two female pilots in the cockpit?
Would it have been more difficult for a female pilot to take over the controls from a male pilot?
Did the copilot understand the captain's question?

Human factors specialists who are involved in accident investigation should not ignore the differences between male and female pilots. There has been a trend to treat female aviators as male pilots since they are performing in a masculine sphere and since they are accepted on masculine terms.

A small survey performed in the RNoAF (♀=5 and ♂=34) indicates, however, a different motivational basis within the sexes for applying for pilot training. While 23 of the males always had had an urge to fly and only to fly, just one of the five females had a dream come true when accepted for pilot training.

When asking the pilots' opinion about why they thought the number of female applicants to pilot training has been so modest, the female pilots point to the lack of role models and information about the training. Twentynine of the male pilots felt that piloting is a masculine profession.

"How will a male copilot respond to a female captain?" Only six of the male pilots could forsee a problem unless the female was less competent than her male counterpart. While the women felt that female aviators have to prove that they are capable of being better!

To the question "What is the ideal pilot like?" The answers from 18 of the males were that he/she should have a high degree of proficiency and good temper, while 13 put ability for cooperation first. Two of the female pilots did not have any answer to this question and three ranked calmness as first priority and ability to react adequately in stressful situations as second priority.

Hegbostad (1989) performed a survey among 20 female commercial pilots in Scandinavia asking why they had chosen piloting as a profession. Of 15 respondents 13 reported that being a pilot was an old dream come true, just like the males in the Air Force. None of the females in this survey had so far experienced any negative attitudes or problems in cockpit. When asked if they had experienced andy difficulties between male and female pilots, nine referred no difficulties, two felt that female pilots had to prove themselves over and over again, while four said that female pilots emphasized safety more than their male counterparts.

The observed differences between the military female pilots and the civilian female pilots may be explained in that the military female pilots have to prove themselves in two areas, the military system and in aviation, as opposed to the civilian female pilot who needs only to concentrate on piloting.
The first generation female aviators are all pioneers and have entered the premises with their eyes wide open. That means they have been prepared and willing to adjust to the special environments of aviation which have been a masculine world. These adjustments are necessary whenever a person enters a new territory and wants to be accepted; one behaves according to the already existing terms.

The starting phase of a new era is not the problem since everybody is alert. It is the second phase that is crucial, because that is when the problems emerge, if any. When it comes to aviation and women, the second phase starts when being a female aviator is not considered exceptional. That will be when the females no longer enter aviation premises on male terms. This will probably coincide with a change of "image" of what "the ideal pilot personality" is like. We foresee that the future image will put less emphasize on courageousness and action and put more weight on teamwork skills and communication abilities from the performers. This statements is not to imply that the next generation female aviators will create problems in contrast to the present generation, but with new requirements in the automatized cockpit, the instructors have to be especially aware of pitfalls which may reduce the effectiveness of the present crew management training.

When giving feedback on performance, instructors should be aware that women tend to attribute failure to lack of ability while men attribute failure as bad luck. Women also show impaired performance when threat of failure is present and when evaluative pressure on a difficult task is increased (Nicholls 1975).

In order to learn how feedback acquires different meanings for the two sexes, one should analyze the pattern of evaluative feed back they experience from various evaluators. Individual differences in attributions result in diffences in the generalization on failure effects. These effects have a more cumulative effect for females than for men and thus provide a way

of understanding why women demonstrate a trend to lag behind boys in achievement areas which probably stems form the different ways boys and girls have been appraised in kindergarten and in school. Broverman & al (1972) have isolated two distinct clusters of traits which are seen as distinguishing men from women.
The first cluster is characterized by warmth, expressiveness, being aware of other peoples feelings and has been associated with women. The second cluster contains traits that reflect competence, dominance and self confidence and has been associated with men. Even after the Feminist movement this general set of stereotypes are being sustained. Stereotypes constitute a set of expectancies for the individual performer which will be reflected in the observers evaluation of the performer.
Deaux (1974) asked employees who held first - level management positions within several organizations to identify the causes for either their success or failures in job related situations. The women in the study made use of "effort" in explaining their success, while the men used "ability" more than effort.

These differences in attribution strategies may also mirror the different communication strategies in men and women. Attributional strategies will influence on communication within a close relationship, i.e. cockpit. Such communication patterns are useful in justifying one's own actions and questioning those of close associates and are evoked primarily in situations of conflicts.

These trains of thought are not reflecting pessimistic minds, but rather an identification of social psychological problems that may rise in the cockpit some years from now for different reasons, one: there will be a change of cockpit setting when beeing a female pilot is not unusual, and two: there will be a trend toward a more androgynous cockpit in the future because the requirement for pilots will be people who give priority to human understanding, who are compassionate and friendly at the same time as they can demonstrate independence, assertiveness and leadership. If selection criteria are changed in order to take care of the new requirements of pilots the present CRM programs may have put emphasise on subjects that will be a matter of course in the future and thus even more time can be spent on the difficult art of communication. This paper is meant as a reminder that the pilot personality is changing along with society, even if some people still thinks that Wolf's "the right stuff" is still what makes a real pilot.

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INFLUENCE DE LA SENSIBILITE INDIVIDUELLE AU STRESS SUR LE COMPORTEMENT (ATTITUDE ET PERFORMANCE) D'EVITEMENT D'ACCIDENT

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Résumé

Le Département des Sciences de l'Environnement de RENAULT étudie le comportement d'un large échantillon de conducteurs (100 personnes des deux sexes, de tous âges et de toute expérience de conduite) impliqués en situation accidentelle (simulation d'une intersection entre deux voies).

Le but est d'analyser la manière dont le conducteur d'une voiture utilise ou non le dispositif d'antiblocage des roues, non seulement pour freiner mais aussi pour effectuer un déport latéral afin d'éviter l'obstacle.

Il apparait que la sensibilité des sujets au stress, évaluée par une approche physiologique pendant les expériences mais aussi par des tests psychologiques réalisés avant et après les expériences, explique pour une part non négligeable la réussite ou pas de l'évitement de l'obstacle.

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Introduction

En 1990, les accidents sur les routes françaises ont entraîné la mort de 10289 personnes (6295 automobilistes). Malgré tous les perfectionnements que l'on puisse apporter aux différents systèmes de retenue (en supposant que tous les usagers utilisent ces dispositifs), et en tenant compte des améliorations encore possibles en renforcement des structures des véhicules, dans 51 % des cas au moins, la violence des chocs est telle qu'elle apparaît au-delà des ressources techniques et économiques connues en sécurité secondaire (THOMAS, 89). Dans ce cas, pour plus de la moitié des accidents, la seule solution relève de la sécurité primaire et de l'évitement de l'accident.

Le système anti-blocage de roues est le système de sécurité primaire le plus prometteur, de la dernière décennie, proposé sur des véhicules de série. A son apparition, certaines compagnies d'assurances ont proposé des primes réduites pour les véhicules équipés de ce système. Après quelques années de recul, ces mêmes compagnies ont supprimé cet avantage car les véhicules concernés ne semblent pas être moins impliqués dans les accidents que les véhicules non équipés. L'avantage du système anti-blocage de roues est pourtant évident : il permet de conserver le contrôle du véhicule durant la phase de freinage, en utilisant au mieux les conditions d'adhérence, et autorise des distances de freinage minimales en toutes situations. Si les performances du système anti-blocage de roues ne sont pas mises en doute, la question de son efficacité sur route reste posée, du moins en terme de réduction du nombre des accidents et des victimes.

Parmi les 37972 accidents corporels impliquant au moins une voiture survenus sur les routes françaises en 1990, 13749 sont des accidents à deux voitures seulement dont 3243 hors agglomération et en intersection. Cette configuration d'accident, qui correspond à un quart des accidents impliquant deux véhicules, semble typique de celle où un système anti-blocage de roues apporterait un gain considérable en sécurité. L'étude décrite dans cet article est basée sur ce type d'accidents.

Protocole expérimental

100 sujets, tous volontaires, ont été recrutés parmi le personnel de Renault. Ils ont été sélectionnés à l'aide de tests psychométriques afin d'évaluer leur émotivité (test de personnalité d'Eysenck et test de stress de Stroop). Les personnes retenues possèdent toutes leur permis de conduire avec une expérience plus ou moins importante mais ne sont pas des pilotes professionnels. Quatre groupes de 25 sujets ont été constitués :

- le groupe 1 dispose d'une voiture qui n'est pas équipée d'ABS.
- le groupe 2 dispose d'une voiture équipée d'un ABS mais n'en est pas informé.
- le groupe 3 sait que son véhicule est équipé d'un système ABS.
- le groupe 4 dispose d'une voiture équipée d'un ABS et a reçu une formation d'une demi-journée. Cette formation comprenait une partie théorique expliquant le but et le fonctionnement du système anti-blocage de roues ainsi qu'une partie pratique constituée de démonstrations et d'exercices d'évitement. La formation a lieu un à deux mois avant les essais.

La répartition des sujets a été réalisée après les tests psychométriques de façon à obtenir des groupes homogènes en âge, en ancienneté de permis de conduire et en émotivité. Le fait de recruter la population d'essai parmi la population active entraîne une sous-représentation des personnes âgées. Plus de 70 % des conducteurs impliqués dans ce type de situation sont cependant représentés.

Parmi les 100 essais effectivement réalisés, 70 seulement ont pu être retenus, soit à cause de défaillances techniques survenues en cours de conduite, soit à cause de configurations "situationnelles" trop différentes de la moyenne. Ces 70 personnes se répartissent de la façon suivante dans les quatre groupes cités ci-dessus : (17 dans le groupe 1; 19 dans le groupe 2 ; 18 dans le groupe 3 ; 16 dans le groupe 4).

Les sujets sont prévenus que l'étude porte sur la sécurité primaire et que leur comportement ainsi que celui de la voiture seront enregistrés durant un parcours de conduite sur circuit pouvant comporter des "situations critiques". La voiture utilisée est une R25 TXI. Pour les sujets du premier groupe, le dispositif anti-blocage de roues est déconnecté, le freinage est donc classique.

Le parcours fermé, constitué de voies de liaisons, de tronçons de circuit et d'une route à deux voies (largeur 7 m) matérialisée par des cônes sur une aire de dégagement. Plusieurs intersections sont traversées par le parcours dont deux dans la partie matérialisée par les cônes. A ces deux intersections, des voitures R19 respectant un "stop" sont arrêtées avec des conducteurs à leur bord. La vision du sujet, au niveau des deux intersections est limitée jusqu'au dernier moment par des murs artificiels et non dangereux (polystyrène, ...) qui masquent les R19 arrêtées. Les autres intersections peuvent être relativement dégagées ou masquées par la végétation.

Le sujet effectue généralement trois tours de circuit afin de se familiariser avec la voiture et le parcours. Le nombre de tours peut varier de façon à ce que les sujets patientant dans la zone d'attente ne puissent évaluer la durée de l'expérimentation. Chaque sujet découvre le circuit quand il commence l'essai et les sujets devant passer n'ont aucun contact avec ceux qui ont déjà effectué le test. La durée d'un tour est de 4 mn et la durée d'un passage est donc d'environ 12 mn. La vitesse de consigne est de 100 km/h dans les lignes droites, 80 km/h da· ·s virages.et 30 km/h dans les voies de liaison Un expérimentateur, toujours le même, est assis à coté du sujet pour lui transmettre les consignes de vitesse et de conduite et s'assurer du respect de ces consignes. L'expérimentateur assure aussi la sécurité du sujet en corrigeant toute manoeuvre pouvant devenir dangereuse.

Durant le dernier tour, la R19 placée à droite de la deuxième intersection est remplacée par un leurre gonflé ayant les formes d'une R19. La voiture du sujet passe devant des barrières optiques qui servent de signal de synchronisation pour le démarrage de l'obstacle. Les murs masquant l'intersection ne permettent au sujet de voir l'obstacle qu'aù moment où celui ci surgit sur leur voie. A cet instant, compte tenu de la vitesse de 100 km/h et d'un temps moyen de réaction estimé à 0,8 s, il manque environ 15 m pour qu'un freinage pur soit suffisant pour éviter l'obstacle. La vitesse moyenne au niveau de l'obstacle est approximativement de 50 km/h. La voiture obstacle traverse la première moitié de la route puis s'arrête. La voie de gauche est libre pour laisser le passage au sujet. Ceci constitue une situation très difficile où la première réaction d'évitement doit être la bonne.

Les paramètres suivants sont enregistrés pendant toute la durée de la conduite :

- débit capillaire
- résistance cutanée
- température cutanée
- potentiel cutané
- fréquence respiratoire
- fréquence cardiaque
- électromyogrammes (EMG) du biceps et du fléchisseur des doigts

- électro-occulogramme (EOG) horizontal et vertical
- une micro-caméra vidéo est fixée sur la tempe droite du sujet pour enregistrer son champ visuel
- une caméra vidéo est fixée sur le coin droit de la planche de bord pour filmer en buste le sujet pendant l'expérimentation

Une quinzaine de paramètres étaient aussi recueillis sur le véhicule mais ils ne seront pas détaillés dans cet article.

Matériels et méthodes

Le propos de cet article étant d'étudier l'aspect physiologique et psychologique du stress du conducteur, on s'intéressera essentiellement aux trois premiers signaux (le potentiel cutané ainsi que les fréquences respiratoire et cardiaque n'étant pas encore analysés). Ces signaux sont recueillis sur l'intérieur de la main gauche, les capteurs étant disposés de façon à ne pas gêner la tache de conduite.

La résistance cutanée (kΩ) est enregistrée en utilisant des électrodes Capsulex impolarisables de 30 mm2, fixées par un sparadrap autocollant sur la deuxième phalange de l'index et du majeur. La résistance est mesurée avec un courant continu. Toute influence entre le potentiel, recueilli au niveau du poignet, et la résistance est éliminée par le fait même du positionnement des électrodes.

Le débit sanguin est mesuré grâce à un Hematron (Dittmar, CNRS/ANVAR brevet n°85 15932), système mesurant en permanence la conductivité des tissus en utilisant le principe de la clairance thermique (diamètre du capteur 25mm).

La température cutanée est mesurée par une thermistance de faible inertie (10K3 MCD2 Betatherm). Un capteur de 4 mm2 est fixé par une glue non caustique sur le milieu de la face interne de la main. Une variation d'environ un centième de degré peut être ainsi détectée. Ces mesures ont pour but d'objectiver la capacité du sujet à utiliser les possibilités du véhicule dont il dispose.

Afin de contrôler l'émotivité globale des sujets confrontés à cette situation, chacun d'entre eux doit remplir un questionnaire d'auto-évaluation (test ASTA) avant et après l'essai. Les différents tests psychométriques permettent : d'une part d'obtenir des groupes homogènes en terme d'émotivité afin de ne pas biaiser les résultats ; d'autre part de déterminer pour chaque sujet son état émotionnel avant et après le test. Les premiers tours de circuit servent à établir des références pour les paramètres recueillis sur le sujet et sur le véhicule par rapport au moment où il aborde l'intersection et sa réaction face à une situation d'urgence.

Résultats

Influence du groupe d'appartenance

On rappelle que la population étudiée est divisée en quatre groupes en fonction de l'information du sujet quant à la présence du système anti-blocage de roues. Les groupes sont homogènes en âge et en sensibilité aux situations stressantes :

- groupe 1 : le système ABS est déconnecté (freinage "ordinaire")
- groupe 2 : la voiture dispose de l'ABS mais le conducteur ne le sait pas
- groupe 3 : la voiture dispose de l'ABS et le conducteur le sait
- groupe 4 : la voiture dispose de l'ABS et le conducteur a été formé

L'influence du groupe est résumée dans la figure 1.

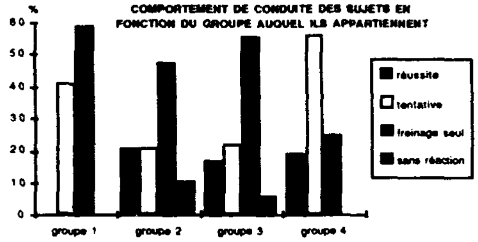


figure 1

Le terme "tentative d'évitement" concerne les sujets qui ont effectué une manoeuvre complexe d'évitement, à savoir freinage et action sur le volant. Même s'ils n'ont pas réussi, une telle manoeuvre était nécessaire pour éviter l'obstacle. Dans ce cas, le choc pouvait être moins violent. Compte tenu de la violence du choc, les sujets du groupe 1 auraient pu être gravement blessés. Les personnes des trois autres groupes ayant tenté un évitement auraient eu des blessures plus légères ou auraient été indemnes. Le but de cet article n'étant pas d'étudier les blessures suivant la sévérité du choc, les auteurs ne détailleront pas plus cet aspect.

Si l'on s'intéresse au comportement du conducteur face à une situation donnée et à sa capacité à utiliser toutes les possibilités d'un système anti-blocage de roues, il faut considérer globalement les barres noires et blanches.

L'intérêt d'un système anti-blocage de roues semble immédiat ; en effet, seul le groupe qui n'en dispose pas n'a pu réussir aucun évitement.

40% des sujets tentent (avec réussite ou non) une manoeuvre d'évitement en tournant le volant. Ce pourcentage passe à 80 % dans le cas des personnes formées pendant une demi-journée aux manoeuvres d'évitement.

Le test a été jugé vraisemblable par la totalité des sujets et seul un très faible nombre ont estimé que l'obstacle n'était pas suffisamment réaliste. Il est à noter qu'aucun des sujets ayant jugé l'obstacle peu réaliste ne l'a évité et tous ont eu une réaction très tardive.

Influence de la personnalité du conducteur

Lors de leur présélection, tous les sujets ont réalisé une série de tests permettant d'évaluer leur personnalité (test d'Eysenck) et leur rapidité de réaction (test de Stroop). Ces tests, réalisés par Mme Pailhous -psychologue-, ont permis de répartir la population étudiée en quatre groupes en fonction de leur capacité à réagir à une situation stressante : A-très peu sensible au stress; B-peu sensible au stress ; C-assez sensible au stress ; D-très sensible au stress. L'influence de ce paramètre est résumée dans la figure 2.

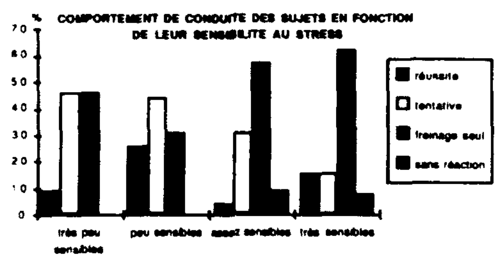


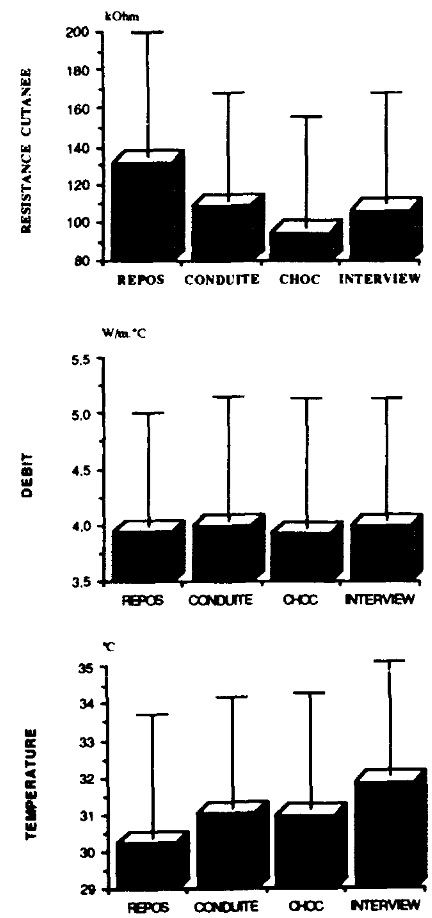
figure 2

La capacité des sujets à effectuer une manoeuvre d'évitement semble très liée à leurs facultés de réactions émotionnelles. Seuls 37% des sujets peu sensibles aux situations stressantes ne réagissent pas correctement puisqu'ils n'associent pas le coup de volant au freinage en voyant apparaître l'obstacle. Parmi les sujets les plus sensibles : les deux-tiers d'entre eux sont soumis à une surcharge émotionnelle les empêchant d'effectuer la bonne manoeuvre.

Physiologie du comportement du conducteur

Les trois paramètres physiologiques présentés (résistance et température cutanés, débit sanguin) ont été enregistrés en continu depuis le moment où le sujet est installé dans la voiture jusqu'au moment où il est interrogé sur ses impressions après le passage de l'obstacle. La valeur de référence au repos est établie quand le sujet est assis dans la voiture à l'arrêt. La valeur de référence de conduite est moyennée sur toute la durée du trajet avant l'apparition de l'obstacle (12 mn environ). La valeur correspondant à l'instant de stress causé par l'apparition de l'obstacle sur la trajectoire est appelée valeur "choc", quelle que soit la performance du sujet. Enfin une valeur dite de "récupération" est mesurée après l'arrêt de la voiture, pendant que le sujet donne ses impressions.

La figure 3 donne les valeurs moyennes (tous sujets confondus) correspondant à chacune de ces phases.



Variation des résistance, débit sanguin et température cutanée au cours des différentes phases de l'expérimentation. Les valeurs sont des données brutes moyennées sur l'ensemble des sujets.

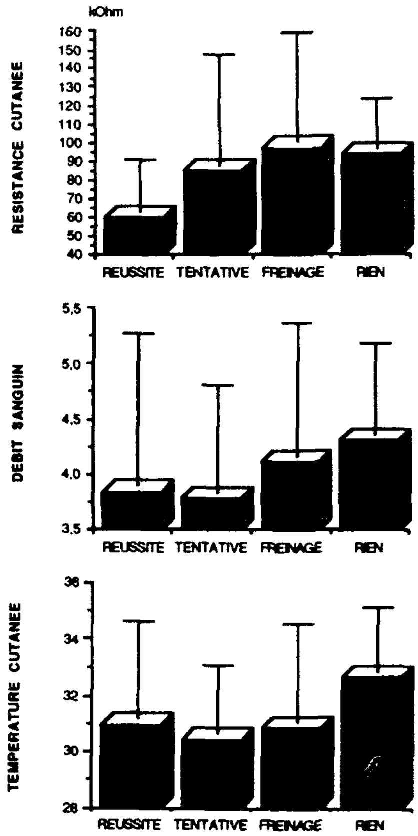
figure 3

Les valeurs les plus hautes de résistance ont été enregistrées au repos, avant le début de la conduite. Dès que la voiture commence à rouler, le sujet se mobilise et sa résistance cutanée baisse de 18% par rapport à la référence de repos. Au moment du choc, la résistance chute de plus de 30% par rapport à la référence, pour revenir ensuite à la valeur enregistrée lors de la conduite, une fois que le stress a un peu diminué. Un retour à la valeur de référence au repos demanderait environ dix minutes.

La température cutanée ne cesse de croître, et ceci probablement pour des raisons dépendantes de la température environnementale. En effet, lors des mesures prises au repos dans la voiture, les portières sont ouvertes pour pouvoir tester tous les paramètres. La température cutanée présente alors les valeurs les plus basses. Pendant la conduite, les vitres sont fermées, la température dans l'habitacle se réchauffe et entraîne une élévation de la température cutanée. Par contre, le choc a un effet suffisamment stressant sur les conducteurs pour stopper instantanément cette élévation constante de la température et de la baisser en une fraction de seconde de près d'un dixième de degré en moyenne. Le choc passé, l'élévation de la température reprend le même cours que précédemment.

Quant au débit sanguin, la valeur au cours de la conduite est plus élevée qu'au repos, comme si les sujets se relaxaient après l'attente du départ. Cependant, il existe un lien certain entre la température et le débit sanguin cutanés, aussi l'augmentation du débit durant la conduite est peut être liée à l'élévation de température précédemment décrite. Par contre, le choc a le même effet stressant que sur les deux autres paramètres et abaisse très rapidement la valeur du débit, qui reprendra sa valeur précédente une fois l'émotion passée.

Ces trois paramètres permettent de bien corréler un état physiologique à un stress dû à un événement particulier. Ceci avait déjà été présenté lors de précédents travaux par Dittmar et al (1985). Pour approfondir l'intérêt de ces mesures, on différencie maintenant les différentes stratégies de conduite : réussite, tentative d'évitement, freinage seul, aucune réaction. Les résultats présentés sur la figure 4 donnent les valeurs des trois paramètres physiologiques lorsque la voiture obstacle s'est engagée sur le croisement.



Variation des résistance, débit sanguin et température cutanée, au moment du choc, en fonction du résultat de la manoeuvre réalisée.

figure 4

Les deux colonnes de gauches représentent les sujets ayant effectué une manoeuvre correcte, réussie ou non. Les valeurs moyennes de chacun des paramètres est plus basse dans le cas d'une manoeuvre adaptée.

Discussion

Les conditions expérimentales correspondent à une situation très critique, une manoeuvre de freinage pur étant insuffisante pour éviter l'accident. Dans une telle situation, l'avantage du système anti-blocage de roues est flagrant. Aucun des sujets n'en disposant pas n'a réussi à éviter l'accident. Le seul fait d'en disposer permet d'éviter l'accident dans 20 % des cas. La formation des sujets contribue à éviter près d'un tiers des accidents.

Dans les trois premiers groupes, 50 à 60 % des sujets n'ont pas essayé de tourner le volant alors que la distance à la voiture obstacle était trop courte pour qu'une manoeuvre de freinage pur soit suffisante. Dans le groupe qui a reçu une formation, 80 % des conducteurs ont réalisé une manoeuvre appropriée. L'amélioration considérable de la performance met en évidence l'utilité d'une formation de ce type (Priez et al. - 1991).

Il peut être surprenant au premier abord de constater que le troisième groupe, informé de la présence du système anti-blocage de roues, obtient de moins bons résultats que le deuxième, non informé. Cette contre-performance peut s'expliquer par une mauvaise connaissance du système anti-blocage de roues et un sentiment de sécurité supplémentaire provoqué par un outil généralement mal utilisé. Ceci est conforté par les interviews réalisées durant les essais, où les sujets décrivent le système anti-blocage de roues comme un dispositif permettant un freinage plus efficace et de meilleure qualité (c'est à dire un freinage optimisé, plus puissant, et une distance de freinage nettement raccourcie en toute circonstance).

Sa capacité à réagir à des situations stressantes ne permet pas de prévoir la performance que réalisera ultérieurement un sujet donné. La qualité de la réaction dépend aussi des conditions émotionnelles et environnementales au moment du test. Dans ce cas, les tests psychométriques permettent d'homogénéiser les groupes lors de leur constitution et d'anticiper sur la qualité de la réaction mais non sur la performance. Les deux tiers des sujets peu sensibles au stress ont correctement évalué la situation et fourni une réaction adaptée. Parmi les personnes sensibles au stress, seul un tiers a pu fournir une réponse adaptée. Pour comprendre la réaction de chaque sujet, il est nécessaire d'en évaluer l'état psychophysiologique en continu. Ceci est réalisé par l'analyse des signaux physiologiques présentés.

Des valeurs élevées de résistance, débit et température sont synonymes de décontraction et chutent lors d'un stress ou d'une forte charge mentale. Ces caractéristiques ont maintes fois été décrites en laboratoire ou sur stade, à l'occasion d'exercices de tir au pistolet (Vernet Maury et al - 1990). Elles se trouvent ici confirmées pendant une phase de conduite automobile et lors d'une situation d'accident. Le fait d'utiliser un grand nombre de capteurs de mesures, uniquement pour évaluer le comportement du conducteur, permet de minimiser l'influence des facteurs externes dans une expérience très bruitée. Il est en effet difficile, voire impossible, d'éliminer dans ce type de test l'influence de facteurs tels que les conditions climatiques, la circulation sur le site d'essais ou même la découverte, pour la majorité des sujets, du site et de la conduite d'une R25.

Les trois paramètres physiologiques étudiés évoluent dans le même sens au cours du test de conduite, avec pourtant quelques différences propres à chacun d'entre eux. Par exemple, la température évolue toujours après une certaine latence par rapport aux autres paramètres. Ce phénomène est simplement dû à l'hystérésis thermique de la peau. Ces variations "inter-paramètres" sont normales car les phénomènes physiologiques enregistrés sont liés mais différents et excluent une redondance systématique.

Par ailleurs, le fonctionnement du système nerveux autonome varie d'un sujet à un autre. Ceci conduit au fait que les moyens à mettre en oeuvre pour l'évaluer devront être adaptés à chaque individu (Lacey et al., 1953). En effet, certaines personnes manifesteront plus leur variation comportementale par une modification de la valeur de résistance alors que d'autres le feront plus par des fluctuations du débit sanguin. Ceci impose une étude en parallèle de l'ensemble des paramètres. Cependant tous les sujets présenteront des valeurs les basses possible de résistance, débit et température en cas de mobilisation de l'attention ou -a fortiori- de stress.

Ceci se retrouve dans les résultats de la figure 3 où l'apparition de la voiture obstacle constitue bien évidemment un stress par rapport à la période de conduite précédente. A ce moment là, pour l'ensemble des sujets, les valeurs de résistance et de débit ont considérablement chuté ; l'élévation constante de la température au cours de tout le test s'est trouvée, elle aussi, stoppée net.

L'étude comportementale conduit à la même conclusion : seuls les sujets dont les valeurs de résistance, débit et température étaient suffisamment faibles se sont bien comportées face au stress (figure 4). Ce qui revient à dire que seuls les conducteurs qui se sont suffisamment investis ont pu réagir correctement. Ou, en d'autres termes, les personnes qui étaient trop décontractées lorsque la voiture obstacle leur a coupé la route, n'ont pu faire face à la situation et sont rentrées dedans de plein fouet .

Les valeurs initiales de résistance cutanée, de débit sanguin et de température cutanée sont intrinsèques à chaque sujet. Les mêmes valeurs seront recueillies d'un examen à un autre si le sujet se trouve dans le même état psychologique (pas de fait émotionnel ou effort physique récent) et se trouve placé dans le même environnement. Cette reproductibilité facilite l'interprétation de plusieurs essais réalisés avec le même sujet. Par contre, dans le cas de l'étude présentée ici, la dispersion des valeurs initiales recueillies d'un sujet à l'autre (correspondant, probablement pour une part, à son degré de décontraction initiale), entraîne de très grandes valeurs d'écart-type. La présentation de données exprimées en terme de variation par rapport à une référence de départ aurait permis de réduire ces écart-types. Les auteurs ont cependant préféré, pour des raisons techniques, présenter des résultats exprimés en valeurs brutes, au détriment d'une variance exagérément grandie et limitant la significativité de l'interprétation. Pour tenir compte de ce fait, les prochains résultats seront exprimés en pourcentage par rapport à une référence estimée soit au repos, soit durant la conduite.

La figure 2 présente l'influence de la sensibilité au stress sur la performance réalisée. La figure 4 présente l'évolution des différents paramètres physiologiques en fonction de cette performance. De même, il serait intéressant de vérifier l'hypothèse immédiate selon laquelle un sujet donné n'aurait pas réagit, ou mal réagit, face à la situation accidentogène car il aurait été paralysé par la peur ou par une surcharge émotionnelle. Malheureusement, la corrélation entre les résultats des tests psychométriques et ceux des mesures physiologiques ne peut pas être faite immédiatement. Les résultats présentés ici ne sont que préliminaires. Le traitement des données continue et diverses méthodes de mise en forme doivent encore être testées. Il convient toutefois de rappeler que des résultats contraires à ceux attendus, voire contradictoires, obtenus avec différents paramètrages du Système Nerveux Autonome (SNA) en réponse à différentes stimulations, ont conduit Mulder (1973) a imaginé que chaque émotion avait son propre profil de réponse du SNA. Cette hypothèse a été prouvée dix ans plus tard par Ekman (1983)

Conclusion

Plusieurs conclusions doivent être apportées. Même si cette partie de l'étude a été peu explicitée ici, il faut souligner l'intérêt de l'ABS. L'efficacité de ce système est réelle. Sa seule présence suffit à sauver les automobilistes placés dans une situation similaire dans 20 % des cas. De plus, une formation adaptée permet d'augmenter considérablement son efficacité.

Un grand nombre de développements peuvent encore être réalisés à partir des données psychophysiologiques recueillies. Il semble notamment intéressant de considérer les variances des paramètres physiologiques en plus de leur niveau. La mise en évidence de relations entre les caractéristiques des sujets révélées par les tests psychologiques et par les réponses physiologiques n'a pu être démontrée jusqu'à présent par la littérature, elle sera peut être facilité par le fait que le sujet est placé en situation critique. De telles relations, si elles existent, permettront, peut être, entre autre, de déterminer si l'hypothèse initiale d'une peur paralysant le conducteur et limitant ses réactions est vérifiée ou non. Il apparaît déjà que même dans des circonstances expérimentales délicates, telles qu'un véhicule se déplaçant sur un circuit où divers événements se produisent, il est possible d'évaluer physiologiquement le niveau de stress d'un conducteur et, a fortiori, pour un sujet impliqué soudainement dans une situation d'accident. Par ailleurs, il est possible de rattacher ces mesures à une notion de performance dans la tache réalisée.

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USE OF MICROPROCESSOR-BASED SIMULATOR TECHNOLOGY AND MEG/EEG MEASUREMENT TECHNIQUES IN PILOT EMERGENCY-MANOEUVER TRAINING

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1. SUMMARY

This paper shows how a combination of microprocessor-based simulator technology and magnetoencephalographic/electroencephalographic (MEG/EEG) techniques is being used in a program of research focussing on the effectiveness of training in precision flying in order to prepare general aviation pilots for emergency situations during take-off and landing. The simulator, representative of a light twin-engine aircraft, affords safe low-cost experimentation. Evoked potentials, obtained with application of MEG/EEG techniques and interpreted within the context of an information-processing model, are expected to add significantly to information obtained from conventional measures of performance and workload. The basic procedure in the series of studies in question involves exposure of experimental groups to simulator-generated formation flying scenarios, with instructions to follow the 'leader' pilot: in subsequent test scenarios requiring take-off and landing under engine failure and turbulent conditions, the performance of experimentals will be compared with that of controls. The paper concludes with a discussion of the safety implications of outcomes for general, military, and commercial aviation.

2. LIST OF SYMBOLS

CNV	Contingent Negative Variation
EEG	Electroencephalography
EF	Evoked Field
EP	Evoked Potential
FTE	Flight Technical Error
GA	General Aviation
IFR	Instrument Flying Rules
MEG	Magnetoencephalography
RT	Reaction Time
TDC	Transportation Development Centre of Transport Canada
VFR	Visual Flying Rules

3. INTRODUCTION

In general aviation (GA), emergency situations such as engine failure or entry into turbulence/windshear conditions - leading as they often do to loss of control resulting in a stall/spin or excessive descent rate of the aircraft (1,2) - are critical during take-off and landing. Under the best of conditions, workload is high for these operations since they require the pilot to process complex inputs to the brain arriving through different sense modalities in the presence of distraction. When emergency situations occur at these times, they can readily lead to accidents not only because they add considerably to normally high workload, but also, and perhaps more importantly, because they do so at a time when proximity to the ground requires extremely prompt corrective action with virtually no margin for error. Serious enough in Visual Flight Rules (VFR) flying, these situations are even more difficult to manage in Instrument Flight Rules (IFR) conditions which, in general, entail still greater workload. The magnitude of the problem is indicated in the most recent reports of GA accidents in Canada, according to which almost 70% of those listed are associated with take-off or landing and, of these, some 30% are indeed due to a loss of contol resulting in stall/spin or excessive descent rate (3,4).

Research comprising a series of studies - sponsored jointly by the Transportation Development Centre (TDC) of Transport Canada, Concordia University, and Simon Fraser University, and now underway in its preparatory stages at Concordia - is examining the possibility that training in precision flying will enhance pilot preparedness for the safe handling of emergency manoeuvers of the kind mentioned above. Although currently the student pilot is provided with some exposure to such situations, training practices nevertheless tend to be conservative, emphasizing avoidance of stall/spins and other unusual aircraft behaviour (5). The underlying notion of the research outlined in this paper is that familiarity with the limits of the safe operating envelope of the aircraft acquired through training in precision flying will not only sensitize the pilot toward early recognition of imminent loss of control, but also equip him/her with the skills needed for quick and safe recovery when a stall/spin or other unusual condition nevertheless occurs. A case in point is found in the report of a recent accident in which incorrect aileron rigging caused a turboprop twin to perform an inadvertent roll in excess of 1-1/4 revolutions (6). The report comments that aerobatic (or precision) flight training could have been a significant factor in avoiding the accident. Another recent example involves a single engine aircraft which was rolled nearly inverted by severe turbulence during landing phase; in this case, correct aerobatic control inputs prevented an accident (7).

A significant feature of the research in question is that it involves use of (a) a low-cost microprocessor-based interactive aircraft simulator developed at Concordia University (8), thus affording a safe environment for experimental procedures and promise of a later safe, cost-effective training tool, and (b) magnetoencephalographic/ electroencephalographic (MEG/EEG) techniques developed by Weinberg (9) that are expected to add precision to measurement of both performance and workload. The combination of the two technologies, currently being applied by Concordia in the development of a driving simulator for TDC (9,10,11), appears readily transferrable to the pilot training situation.

In the paragraphs below, descriptions of the simulator system and the MEG/EEG measurement approach are followed by an overview of experimental procedures. The paper concludes with a brief description of expected outcomes of the study and their implications for aviation training and accident avoidance.

4. THE CONCORDIA SIMULATOR SYSTEM

As the simulator is fully described in other literature (8), the account presented here is only that which is sufficient for an understanding of how it is being used in the research on emergency manoeuver training. Figure 1 shows the system components, these comprising (A) simulator environment, (B) 'main frame' microcomputer, (C) graphics work station, (D) experimenter/instructor work station, (E) performance measurement module, and (F) subject/trainee. The simulator cabin has the appearance of a Beech Duchess. In addition to functioning flight instruments, the cabin is also equipped with instrumented controls, force-feel being provided by a semi-active pneumo-hydraulic system. A video projector and a 50°-horizontal/40°-vertical screen, as well as speakers with audio amplifiers driven by digital boards with sound-storing/recall capability, complete the simulator environment.

The 'main-frame' computer comprises an Intel SBC640 and an Olivetti M24 microprocessor which, together, accommodate the flight dynamics model, provide input/output functions, and allow the experimenter /instructor to interact with the simulator. The graphics station houses an Iris 3120 which acts on output from the flight dynamics model to generate the interactive scene viewed by the subject/trainee. The experimenter/instructor work station is equipped with a keyboard for input to the main frame and the Iris, along with a monitor displaying subject performance output. The performance assessment module holds a data acquisition system for collection of both behavioural and electro-physiological data generated by the subject/trainee, circuitry for EEG signal conditioning, and an Olivetti M280 microprocessor which processes the data.

Although the simulator has no motion base, validation tests with experienced pilots in the Concordia Laboratory have produced very positive results in terms of operational fidelity (12). With avionics based on the Bendix/King Silver Crown system, the instrument panel is representative of a well equipped light twin-engine aircraft. Although mechanically based and therefore not easily reconfigured, the displays are software driven, thus allowing for substantial flexibility in programming different waypoints/approach fixes and of adjusting the sensitivity of the display heads. Utilizing data for both the Beech Duchess and the Grumman Cougar, the aircraft model is based on flight dynamics principles - as is the case for large-scale simulators - so that the flight characteristics of different airplane configurations and types, as well as system failures, can be easily simulated. On balance, then, the Concordia flight simulator is a very suitable device for carrying out research on manoeuvers too dangerous to conduct in the field, while its use of low-cost microprocessor technology renders it promising as a safe, cost-effective part-task trainer for such manoeuvers.

5. MEG/EEG MEASUREMENT APPROACH

5.1 The Information-Processing "Time Line" Model

By generating information not available in behavioural measures such as reaction time (RT), deviation from track, numbers of errors, and so on, use of MEG/EEG technology to obtain direct measures of brain function is expected to add measurement precision in the research described later in the paper. A brief description of the information-processing model will assist in understanding why this is so. This model holds that human responses to external situations are determined by the flow of information through the brain (13). It is commonly agreed that this flow consists of events such as attention, detection, short- and long-term memory storage, form discrimination, recognition, interpretation, decision as to the response, and preparation of an overt response. The term "flow" seems to imply that the overall process is linear. However this is far from true; rather it appears to involve many feedback and feed-forward loops and, further, is influenced by motivation and the general state of arousal of the brain. Nevertheless, it is convenient to think in terms of an information-processing time line as representing what happens between input and output. Also, it is clear that data relating to events along this time line would provide extremely useful information regarding how well an individual is processing information from stimulus input.

5.2 Use of EEG and the Information-Processing Time Line

In the study at hand, evoked potentials (EPs) are being used to obtain information about cognitive events. These wave forms reflect changes in electrical activity in the brain occurring in response to a physical or cognitive stimulus; because they are so small, they must be extracted from the noise of the ongoing background EEG by a signal averaging process (14). Evidence exists to the effect that endogenous EPs (those whose latency, morphology, and amplitude are dependent only on cognitive stimuli) can be indexed to cognitive events in the brain (15). Figure 2 illustrates in idealized form how these wave forms can be related to the information-processing time line along which, according to the model, such events occur. Characteristics of certain EPs - principally P300 and the contingent negative variation (CNV) - are being used with the TDC driving simulator as measures of perceptual and cognitive capability for the assessment of driving potential (9). Success in this instance, as well as in previous research (16), augurs well for their use, in combination with various behavioural indices, as measures of performance in both the training and test conditions of the aviation studies in question. Further, in light of evidence indicating promise for EEG approaches in the everlasting search for more reliable measures of workload - especially in terms of their non-intrusiveness and ability to show increases in stress of which the pilot is unaware (17) - EPs will be used also to measure the effects of workload manipulations during test and training conditions.

Finally, because use of EPs implies that a testee's problems in responding to stimuli can be pin-pointed to events on the information-processing time line, it follows that amplitudes and latencies of these wave forms contain the essential information for designing cognitive training exercises specifically tailored to an individual's needs, and for assessing progress as practice takes place. For example, if it were inferred from low amplitude P300 responses that an individual's poor external performance was due to difficulty in updating memory, then that individual could be administered specially designed memory update tasks, and his or her progress during practice could be monitored by examining the amplitude of P300 responses. Accordingly, EPs will be used in this context in the emergency manoeuver research discussed in an exploratory attempt to determine whether a cognitive training procedure might be a cost-effective way of bringing deficient performance up to an acceptable level.

5.3 Use of MEG Technology

Unlike volume currents, magnetic fields (which result from the electrical fields producing the EPs), are not attenuated or distorted as they pass through the tissues of the head. For this reason, evoked fields (EFs) generate even more accurate signals than do EPs about information processing taking place in the brain, and source localization is more accurate (16). Unfortunately, however, MEG apparatus at this stage of its evolution is extremely cumbersome, consisting as it does of (i) a gantry system supporting a large dewar containing superconducting sensors, a noise balancing system, and liquid helium that cools the superconducting materials to room temperature, as well as of (ii) computers for controlling the gantry and processing the data. Figure 3 shows a diagrammatic representation of the dewar for a 100-channel system being developed by CTF Systems Inc. and the Brain Behaviour Laboratory of Simon Fraser University (with funding assistance from the Defence and Civil Institute of Environmental Medicine, TDC, the Department of Supply and Services, and the B.C. Institute of Science and Technology). Because in the case at hand this apparatus resides in Vancouver while that for the simulator is in Montreal, MEG techniques will be used largely for source localization purposes, the aim being to assist in reducing the number of electrodes required for EP data collection and to arrive at their configuration. To this end, paradigms for experiments using the simulator will be mocked up and simplified to a degree manageable with the MEG apparatus. Some EP/EF comparisons will, however, be made.

6. PRELIMINARY RESEARCH DESIGN APPROACHES

The series of experimental studies comprising the emergency manoeuver training research program is now only in its preparatory stages during which system modifications are being made, integrating software is being developed, training and test scenarios are being designed, relevant graphical experimentation is being undertaken, and procedures for the various studies are being structured and refined. What can be said about the research design at this writing is, first, that experimental and control groups will be involved in training and test conditions. Basic procedures will require experimental pilots to be 'trained' through exposure to simulator-generated formation-flying scenarios under various levels of workload, their task being to follow a 'leader' pilot. Control pilots having the same level of experience as experimental counterparts are to be exposed for an equal length of time under the same levels of workload to different scenarios, each of these involving a task unrelated to precision flying. Subsequently, both groups will undergo testing on flying performance during exposure to scenarios requiring take-off and landing under conditions of engine failure and extreme turbulence. Both VFR and IFR conditions are being incorporated into the overall design. Workload manipulations - to be imposed at normal, moderate, and high levels - include, but are not limited to, those involving approach geometry and sensitivity of the instrument panel.

In the training condition, the main dependent variables are RT to cue stimuli and deviation from the flight path of the 'leader' pilot - in the test condition, RT to cue stimuli and deviation from the flight path of an unseen 'expert' pilot. Other important performance variables, those relevant to flight technical error (FTE), include cross track error and variation in airspeed, altitude, and heading. In all cases, these data will be analyzed and interpreted (likely using some sort of neural net model) in combination with amplitudes and latencies of P300 and the CNV, the paradigms being set up for interpretation of the former as memory update, the latter as attention, general capacity to perform, and degree of workload experienced. Although the main thrust of the study will be to determine the effectiveness of training in precision flying in handling emergency flight conditions, considerable attention will also be given to the relationship of workload to FTE. Additionally, as mentioned earlier, amplitudes and latencies of P300 and the CNV will be used to design cognitive training exercises specifically tailored to problems of deficient performers and to monitor their performance during practice of these exercises. The aim here is to make a preliminary assessment of the utility of this approach in bringing such performers up to acceptable levels.

7. CONCLUSION

The authors, all of whom have flying experience, strongly suspect that outcomes of the study will support the contention that training in precision flying would indeed enhance pilot ability to handle emergency situations resulting in unintended aircraft behaviour under both VFR and IFR conditions. The obvious implication for general aviation relates to a possible modification of existing training curricula. However it is expected that outcomes will permit generalization to military and commercial training practice. The studies are expected also to demonstrate the effectiveness of EPs (i) as measures of not only performance but also of pilot workload, particularly as it relates to distraction, avionics display design, and the geometry of landing approaches, and (ii) as keys to the design of cognitive training exercises that, by bringing less-than-optimal performers up to acceptable levels, may reduce costs of training.

Another extremely important outcome of the series of studies relates to the simulator technology itself. Systems engineering carried out in order to configure the simulator suitable for experimental procedures will in fact have rendered it a prototype part-task simulator for safe, cost-effective training and testing in the area of emergency situations. The singular advantage of such a tool is that it allows the student pilot to undertake frequent practice at his/her own pace without harm to self or aircraft and, thereby, to acquire operational skill important for accident prevention in an efficient cost-saving way.

In sum, it is anticipated that innovative application of the microprocessor simulator technology combined with MEG/EEG measurement techniques will generate a wealth of information with important implications for safety in the areas of general, military, and commercial aviation.

8. ACKNOWLEDGMENTS

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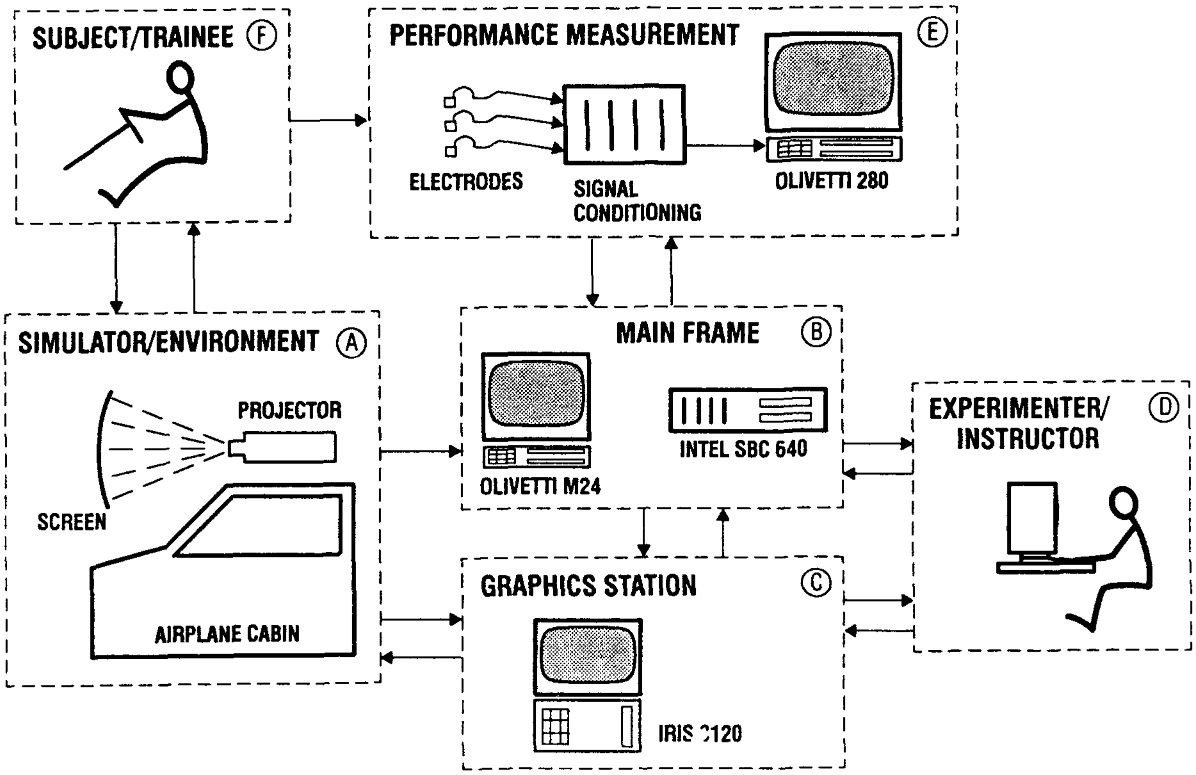

Figure 1. Simulator System Components

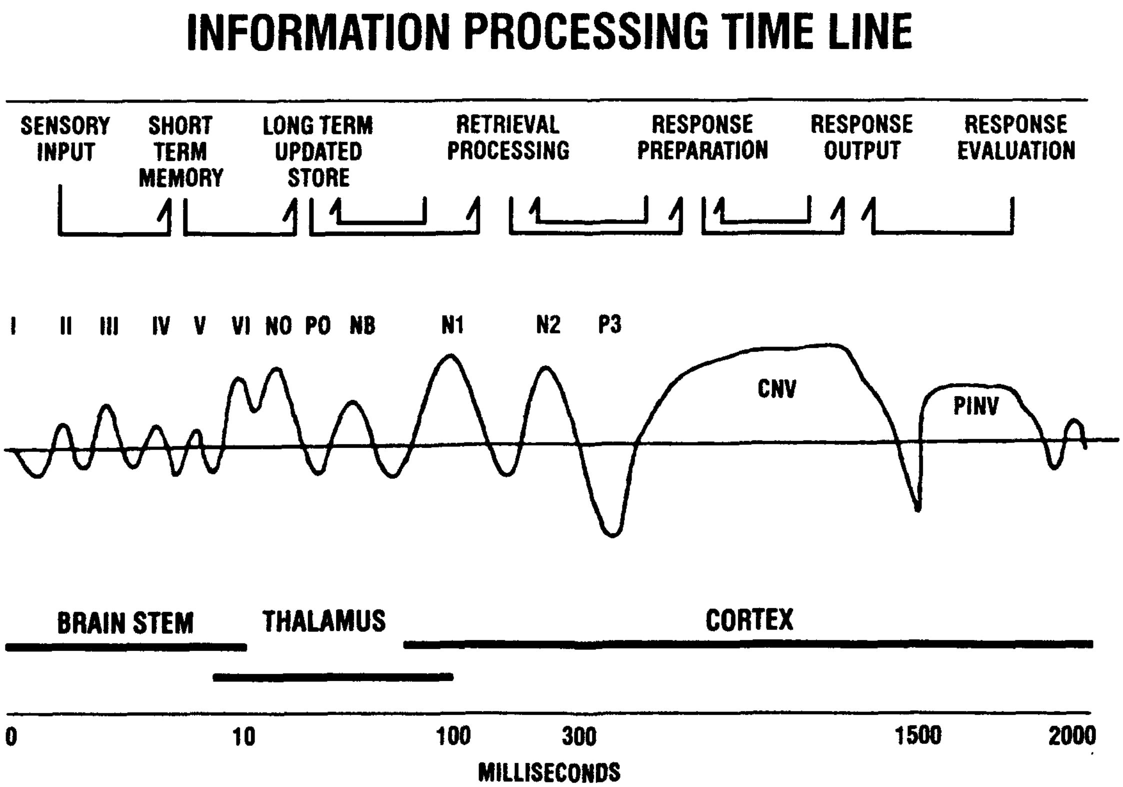

Figure 2. Idealized Evoked Potentials (EPs) in relation to the Information-Processing Time Line

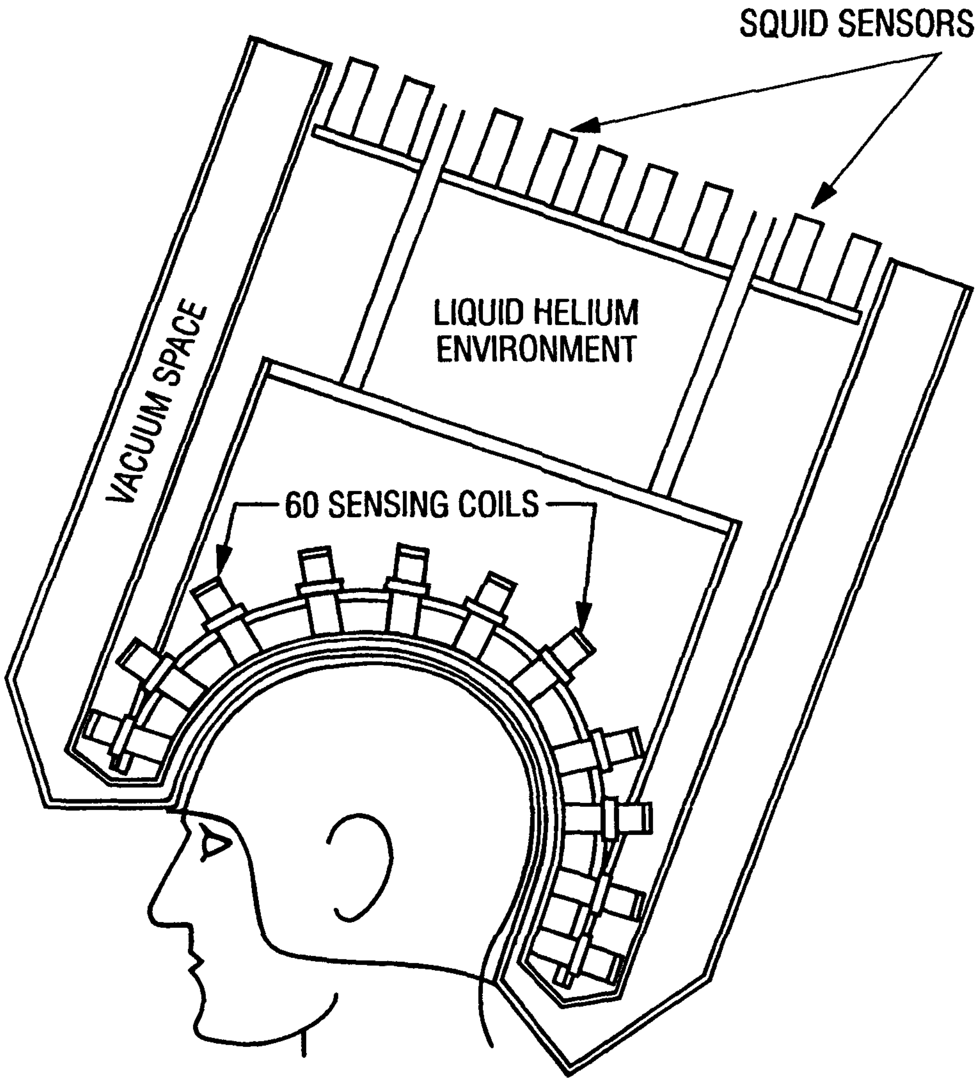

Figure 3. Schematic Representation of a 60-100 Channel MEG System

ETUDE DU SPECTRE DE PUISSANCE DU RYTHME CARDIAQUE AU COURS DE TACHES RELATIVES A LA SECURITE DE LA CONDUITE DE L'APPAREIL

par

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ABSTRACT

Le relâchement de l'attention du sujet accroît la probabilité de survenue d'erreurs mineures dont l'absence de détection et l'accumulation sont susceptibles de conduire à l'incident.

Mulder, Vicente, Moray et d'autres auteurs ont montré l'intérêt de l'étude du spectre de puissance du rythme cardiaque, et plus particulièrement de la bande de fréquence 0.05 - 0.15 Hz dans l'évaluation de l'effort mental du sujet. Nous avons précédemment montré l'existence d'une correspondance entre des mesures de la variabilité cardiaque dans le domaine temporel, et l'évaluation subjective de la charge de travail du pilote. Celle-ci est essentiellement une charge de travail mental, dont les principales composantes sont la pression du temps, le stress et l'effort mental.

Nous avons poursuivi cette étude du rythme cardiaque du pilote, dans le domaine fréquentiel, et développé un programme d'analyse du spectre de puissance de la fréquence cardiaque tenant compte des limites apportées par l'étude d'un signal discret. L'enregistrement de la fréquence cardiaque est effectué au moyen d'un système de monitoring ambulatoire et associé à une observation synchrone de l'activité du sujet.

Cette méthode a été appliquée à des enregistrements effectués au cours de tests psychophysiologiques en laboratoire et au cours de situations réelles de pilotage de différents appareils. Les résultats obtenus montrent la sensibilité de l'énergie spectrale du rythme cardiaque dans la bande de fréquence 0.05 - 0.15 Hz, à l'effort mental du sujet.

Cependant, l'énergie spectrale dans cette bande de fréquence n'est pas corrélée à la difficulté de la tâche, ni à la performance.

Certains sujets relâchent leur effort mental lorsque la difficulté de la tâche leur parait excessive, d'autres le maintiennent ou l'augmentent sans pour autant améliorer leur performance.

L'augmentation ou l'absence de diminution de l'énergie spectrale du rythme cardiaque devant une tâche de difficulté accrue, ou lors de tâches relatives à la sécurité du pilotage de l'appareil pourrait constituer un facteur favorisant la survenue d'erreur et augmentant la probabilité d'incident ou d'accident.

CONTRIBUTION DE L'ANALYSE DE L'ACTIVITE OCULAIRE (COMPLEMENTAIRE DE L'ANALYSE ELECTROENCEPHALOGRAPHIQUE) A LA DETECTION DES BAISSES DE VIGILANCE DANS LES TACHES DE PILOTAGE DE VEHICULE

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RESUME : Le Département des Sciences de l'Environnement de RENAULT étudie un système de détection des baisses de vigilance du conducteur. Embarqué dans le véhicule, celui-ci aura pour rôle de prévenir le conducteur de toute détérioration de son état de vigilance. Le principe est basé sur l'analyse en temps réel des mouvements que le conducteur impose à son volant. La conception d'un tel système nécessite, dans une phase d'étude, de connaître à tout instant le niveau de vigilance du sujet à partir de signaux physiologiques, ceci afin de déterminer les paramètres du signal Angle Volant qui seront aptes à s'y substituer pour distinguer deux états de vigilance. Nous exposons ici une méthode permettant la définition d'une référence physiologique du niveau de vigilance du conducteur, fondée sur l'approche complémentaire de l'électro-encéphalographie (EEG), de l'électro-oculographie (EOG) et de l'analyse comportementale par l'imagerie vidéo. L'analyse de l'évolution des schémas oculographiques améliore significativement la détection précoce de l'hypo-vigilance. Grâce à la connaissance de cette référence physiologique, nous présentons ensuite les résultats obtenus sur le signal Angle Volant en terme de détection de l'hypo-vigilance.

1 - INTRODUCTION

La fatigue est responsable en France de 26 % des accidents mortels survenant sur autoroute. La perte de contrôle du véhicule peut être la conséquence d'un assoupissement dont le conducteur n'a pas pris conscience suffisamment tôt, malgré l'existence de nombreux signes précurseurs de cet état. Le Département des Sciences de l'Environnement de RENAULT étudie actuellement un système embarqué de détection des baisses de vigilance dont le but est de prévenir le conducteur le plus tôt possible de toute détérioration de son état de vigilance. Cette aide à la conduite ne doit pas exiger de la part du conducteur de tâche supplémentaire spécifique à la surveillance de l'état de vigilance, mais doit être inhérent à la tâche de conduite. Le principe est basé sur l'analyse en temps réel des mouvements que le conducteur impose à son volant. Un micro-processeur compare à tout instant les valeurs prises par certains paramètres issus du signal Angle Volant, avec les valeurs d'une référence dite de "Haute Vigilance", enregistrée par exemple en début de parcours. Les paramètres choisis doivent être caractéristiques des différences existant entre un signal de haute vigilance et un signal de basse vigilance. Ils mettent notamment en évidence les modifications intervenant sur la précision des corrections de cap [1].

Nous développons ici la phase d'étude d'un tel système, visant à obtenir une référence physiologique fiable du niveau de vigilance du conducteur. En effet, ce niveau doit être connu de façon objective afin d'être en mesure de déterminer les paramètres issus du signal Angle Volant, suivant au mieux les fluctuations de la vigilance [2]. Nous allons donc présenter une méthode d'analyse des signaux physiologiques fournissant le niveau de vigilance, à partir d'enregistrements réalisés sur simulateur de conduite.

2 - PROTOCOLE EXPERIMENTAL

Les essais se sont déroulés sur le simulateur de conduite Suédois du VTI (Vehicule Traffic Institute) afin d'obtenir sans danger et en peu de temps des baisses de vigilance marquées. Avec 4 degrés de liberté, ce simulateur permettait aux sujets de ressentir des impressions proches d'une conduite réelle.

27 sujets agés de 22 à 56 ans (moyenne = 30,5 ans, écart-type = 8,18), dont 16 hommes et 11 femmes ont été selectionnés sur leur propension à émettre des ondes alpha les yeux fermés. La durée maximale de conduite était fixée à 3 heures mais pouvait être plus courte si le sujet effectuait une sortie de route de longue durée, ce qui stoppait le simulateur. Un film de route très monotone à 2 voies, sans intersection ni véhicule, réalisé par images de synthèse leur était projeté. Le parcours consistait en un circuit bouclé d'une longueur de 36 Km, comprenant 70 % de lignes droites et 30 % de virages à

très grand rayon de courbure. La consigne donnée aux sujets était de maintenir le véhicule sur la voie de droite à une vitesse comprise entre 100 et 120 Km/h.

Deux séries de signaux était enregistrées sur bande magnétique :

- des signaux mécaniques : Angle Volant, vitesse volant, vitesse du véhicule, couple volant, courbure de la route, frein, clignotants, position latérale du véhicule
- des signaux physiologiques : 2 voies EEG pariéto occipitales, 2 voies EOG (verticale et oblique)

De plus, une caméra filmait pendant tout l'essai le visage du conducteur, ainsi que ses bras et la partie supérieure du tronc. Ce film permet la détection de l'hypovigilance grâce à une analyse comportementale.

Nous disposons donc d'une importante banque de données qui nous permet, dans un premier temps, d'établir une référence physiologique du niveau de vigilance du conducteur. 9 sujets sur 27 se sont endormis et sont sortis de la route : leur durée de conduite varie entre 46 minutes et 2 heures 16 minutes. Les 18 expérimentations restantes (sans endormissement) ont duré entre 2 heures et 2 heures 58 minutes. Ces enregistrements nous donnent donc la possibilité d'étudier tous les stades de vigilance entre l'éveil et le sommeil.

3 - ETABLISSEMENT DE LA REFERENCE PHYSIOLOGIQUE FOURNISSANT LE NIVEAU DE VIGILANCE

3-1 INDICES PHYSIOLOGIQUES PERTINENTS

De nombreux auteurs ont décrit les modifications intervenant notamment sur les signaux électro-encéphalographiques (EEG) et électro-oculographiques (EOG) lorsque la vigilance décroît.

Le signal EEG est classiquement utilisé comme indicateur du niveau de vigilance d'un sujet [3], [4], [5]. En effet, de nettes modifications du contenu fréquentiel de ce signal sont observées lors du passage de l'éveil à un stade d'hypovigilance, puis à la somnolence et enfin au sommeil. Pour les stades d'hypovigilance et de somnolence qui nous intéressent, l'analyse des bandes de fréquence bêta (12 à 25 Hz), alpha (8 à 12 Hz) et thêta (4 à 8 Hz) semble la plus adaptée. Un ralentissement des ondes cérébrales, exprimé par une augmentation du pourcentage des ondes alpha au détriment des ondes bêta caractéristiques de l'éveil actif est observé en concomittance d'un déclin des performances. Les corrélations entre la performance et les indices EEG sont significatifs : elles sont positives avec l'activité bêta et négatives avec les activités alpha et thêta.

Les caractéristiques du signal EOG se modifient également énormément en fonction du niveau de vigilance [4], [6], [7], [8]. Les mouvements oculaires lents (MOL) s'avèrent être l'un des signes les plus caractéristiques de la phase de transition entre l'éveil et le sommeil. Différents des mouvements oculaires volontaires de l'éveil, ils sont décrits comme des mouvements pendulaires de gauche à droite [7] et sont associés à une convergence des yeux. Sur le signal EOG, ils se traduisent par des déflexions lentes durant plus d'une seconde et d'au moins 100 microvolts d'amplitude [6]. Leur détection est optimisée par l'emploi de dérivations EOG horizontales ou obliques qui sont des composantes très sensibles aux variations fines de la vigilance [8]. Les MOL sont détectés en grand nombre lors du stade 1 de sommeil mais apparaissent également durant la longue période séparant l'éveil du sommeil [7]. Leur amplitude est modérée au départ mais augmente avec le degré de somnolence [4]. Sur des conducteurs de train effectuant de longs trajets, il a été remarqué que la proportion des MOL augmentait nettement avec la survenue de la somnolence, alors que le nombre de clignements palpébraux diminuait [6]. Des études en laboratoire ont montré que le pourcentage de MOL croît continûment pendant toute la période d'éveil précédent le stade 1 de sommeil, qu'il reste constant et élevé pendant tout le stade 1 puis décroît lors du satde 2 [7]. D'autres auteurs décrivent les activités oculaires d'éveil comme des mouvements amples, rapides et très fréquents (clignements palpébraux, mini-saccades). Le début de la période de transition fait apparaître des mouvements oculaires lents d'amplitude moyenne, la fréquence des clignements diminue. Le véritable stade de somnolence est caractérisé par des MOL de grande amplitude [8]. La transition entre l'état de veille et le stade 1 du sommeil est donc ponctuée par une séquence d'évènements oculaires dont la première manifestation est la disparition des mouvements caractéristiques de l'état de veille active.

Il semble donc qu'une définition correcte de cette période de transition ne puisse se baser uniquement sur le signal EEG et que l'analyse simultanée du signal EOG soit indispensable à l'obtention d'une définition électrophysiologique fiable [4].

3-2 ETUDE COMPORTEMENTALE

En complément de l'analyse des signaux électro-physiologiques, l'étude du facteur comportemental s'avère être un puissant outil pour la détection de l'hypovigilance. Dans notre cas, les différentes manifestations comportementales peuvent être enregistrées en filmant en continu le visage du sujet ainsi que les segments corporels impliqués dans la tâche de conduite. A partir de ce film, une liste des comportements peut être établie.

Que ce soit dans le domaine de l'éthologie ou de l'ergonomie, de nombreux auteurs se sont intéressés à l'analyse comportementale et ont décrit un certain nombre d'activités subsidiaires non nécessaires à la réalisation de la tâche demandée [9], [10] :

- activités ludiques
- mouvements de confort : différents ajustements de position
- mouvements auto-centrés ou autistiques [11]. Ce type d'acte moteur correspond à un mouvement de l'une ou des deux mains du sujet vers son propre corps (grattement, tapotement, rongement des ongles par exemple).

L'étude de ces activités subsidiaires, également qualifiées de collatérales [12], s'avère d'un grand intérêt pour la compréhension des effets d'une tâche répétitive et monotone. Elles sont souvent considérées comme le reflet de l'inadéquation entre les capacités du sujet à un instant donné et la tâche demandée.

3-3 RESULTATS

Nous présentons ici une méthode permettant la caractérisation du niveau de vigilance du sujet. Celle-ci est basée sur l'analyse d'une part des signaux EEG et EOG qui contiennent, comme nous l'avons vu précédemment, une grande part de l'information recherchée, d'autre part du film vidéo représentant le conducteur. L'association de ces trois sources d'information doit pouvoir permettre d'accéder de manière fiable au niveau de vigilance recherché. Cette méthode est entièrement manuelle, nous n'avons pas cherché à effectuer un traitement automatisé. En effet, l'établissement de la référence physiologique peut être réalisé en temps différé, en laboratoire, puisqu'elle ne concerne que la phase d'étude de notre système. D'autre part, l'analyse comportementale ne peut techniquement pas être envisagée de façon automatique à l'heure actuelle, alors qu'un traitement manuel fournit des résultats fiables.

La méthode consiste dans un premier temps à étudier en détails le film vidéo : très riche en informations, il comporte un grand nombre d'indices comportementaux permettant de décrire l'état de vigilance. Nous construisons ainsi un éthogramme en codant chaque item comportemental puis en le transcrivant directement sur le tracé des signaux EEG et EOG. Nous disposons donc à tout instant de la correspondance entre l'aspect comportemental et l'aspect physiologique. Une analyse des signaux EEG et EOG est ensuite pratiquée et l'ensemble de ces résultats permet de définir une classification en cinq niveaux de vigilance.

Analyse comportementale

En général, le comportement du sujet évolue nettement au cours de l'expérimentation. En début d'essai, le sujet est concentré sur ses tâches : maintien de la trajectoire et maintien de la consigne de vitesse. Il regarde soit la route, soit le compteur vitesse. Il se tient droit, les deux mains placées sur le volant. Ce sont des périodes de grande activité, pendant lesquelles le sujet est tonique, tout particulièrement pendant la phase d'apprentissage des tâches.

Un épisode d'hypo-vigilance est caractérisé par une modification de ce comportement. On peut alors observer différents phénomènes qui apparaissent de plus en plus souvent au fur et à mesure que la vigilance baisse et qui montrent que l'attention du sujet se porte progressivement sur des points autres que la tâche qui lui a été fixée :

- mouvements sur le siège : redressements, modifications de la posture et de la position par rapport au dossier et à l'appui-tête
- mouvements des bras : modification de la position des mains sur le volant, conduite d'une seule main
- mouvements de la tête : regards vers l'extérieur, recherche d'un autre centre d'intérêt que la route
- mouvements auto-centrés bâillements, soupirs ...

La fréquence des regards vers le compteur vitesse, indiquant que le sujet est concentré sur la consigne de maintien de la vitesse, est également un indice révélateur du niveau de vigilance. En effet, on observe que la diminution du nombre de ces regards est étroitement liée à l'apparition de l'hypovigilance et associée à une nette augmentation de la variabilité de la vitesse autour de la valeur de consigne.

Analyse du signal EEG

Elle est effectuée de façon classique. L'apparition de la somnolence est indiquée chronologiquement par une diminution du taux d'ondes bêta suivie de l'apparition des ondes alpha, puis de leur disparition progressive au profit des ondes thêta.

Analyse du signal EOG

L'ensemble des évènements suivants peut être repéré sur le signal EOG au cours d'un essai :

- clignements palpébraux
- fermetures franches de paupières
- regards à droite ou à gauche
- regards vers le compteur vitesse
- rotations des yeux lors d'épisodes d'hypo-vigilance (associés ou non à des MOL).

La raideur des fronts de montée et de descente du signal renseigne sur la rapidité des mouvements. Cet indice est généralement bien révélateur du niveau de vigilance. La **Figure 1** présente des exemples typiques de quelques mouvements oculaires.

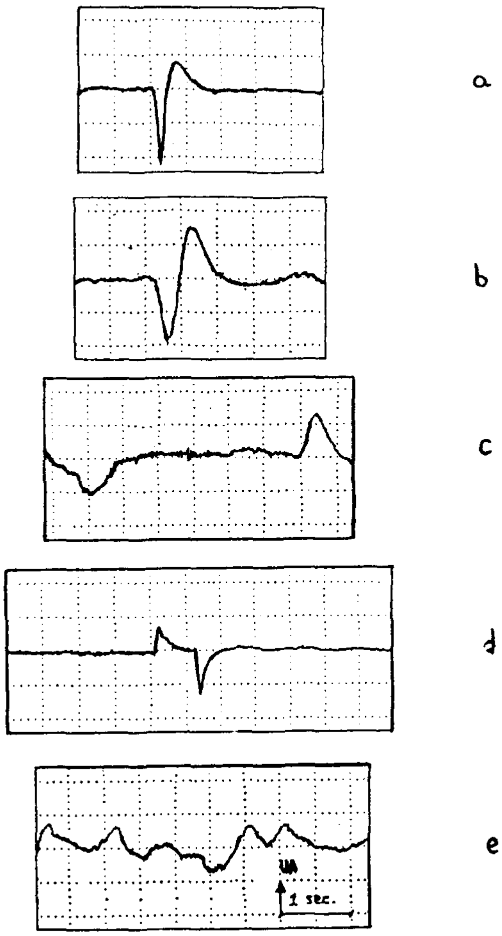

Figure 1 : Les différents mouvements des yeux traduits sur le signal EOG (sujet n° 2) - **a** - clignement palpébral
b - fermeture de paupières avec temps d'arrêt yeux fermés très court - **c** - fermeture de paupière de plus de 2,5 sec.
d - contrôle compteur vitesse
e - rotations des yeux lors d'un épisode d'hypo-vigilance, associées à des fermetures partielles

La nature des évènements oculaires se modifie fortement en fonction de la vigilance. Un tracé de haute vigilance ne comporte que des clignements palpébraux et des regards vers le compteur vitesse. Les mouvements sont rapides, les fronts de montée et de descente sont presque verticaux. En basse vigilance, le tracé est plus complexe car différents mouvements oculaires sont combinés entre eux. Les clignements palpébraux font place à des fermetures franches de paupières. Tous les schémas oculaires sont déformés. Les déplacements deviennent lents et les yeux sont en perpétuel mouvement dans une lutte contre le sommeil. Des MOL apparaissent. Entre ces deux stades, les modifications sont progressives. L'analyse de l'EOG permet donc de bien suivre la dégradation de la vigilance. La **Figure 2** illustre l'apparition de l'hypo-vigilance.

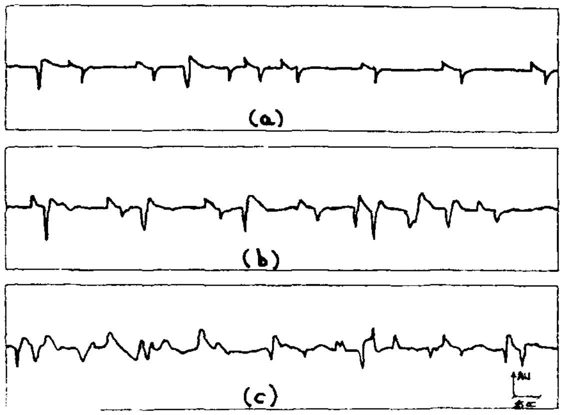

Figure 2 : Signal EOG enregistré après :
a - 5 min 46 sec de conduite
b - 30 min 13 sec de conduite
c - 1 h 8 min 22 sec de conduite
(sujet n° 2 s'étant endormi après 1 h 10 min d'essai)

Classification en niveaux de vigilance

Cette classification doit être établie en continu sur tout l'essai, de façon à connaître à tout instant le niveau de vigilance du conducteur. Nous définissons 5 niveaux :

- **Niveau 1** : Haute vigilance. Le conducteur est en plein possession de ses moyens
- **Niveau 2'** : Niveau d'hypo-vigilance très précoce (premiers signes)
- **Niveau 2** : Niveau d'hypo-vigilance précoce
- **Niveau 3** : Niveau d'hypo-vigilance prononcée
- **Niveau 4** : Stade final. Le conducteur semble dormir

Pour les expérimentations courtes, se soldant par une sortie de route après endormissement, on observe rapidement une modification du comportement signifiant que la vigilance baisse. Plusieurs schémas peuvent alors se rencontrer :

- la vigilance décroît continûment jusqu'à la fin de l'essai
- le conducteur passe par des phases importantes de récupération, plus ou moins longues et plus ou moins nombreuses.

Sur les expérimentations longues, stoppées après 2 heures 30 minutes ou 3 heures de conduite en l'absence d'endormissement, certains sujets ne montrent pratiquement aucun signe d'hypo-vigilance. D'autres traversent des phases de vigilance amoindrie, sans atteindre les niveaux aboutissant à l'endormissement. D'autres commencent à s'endormir jusqu'à ce qu'un début de sortie de route ne les réveille.

On remarque une grande variabilité inter-individuelle quant aux classifications obtenues. Celles-ci sont caractéristiques du comportement personnel d'un sujet face à la tâche qui lui a été attribuée.

Les **Figures 3 et 4** fournissent quatre exemples de classifications obtenues sur des sujets différents.

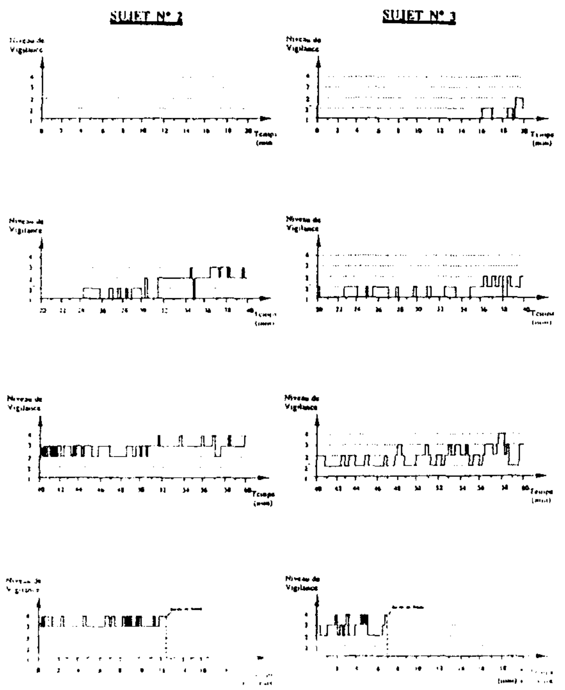

Figure 3 : Classifications physiologiques des sujets n ° 2 et 3
Cinq niveaux de vigilance
Les sujets sont tous les deux sortis de la route après endormissement

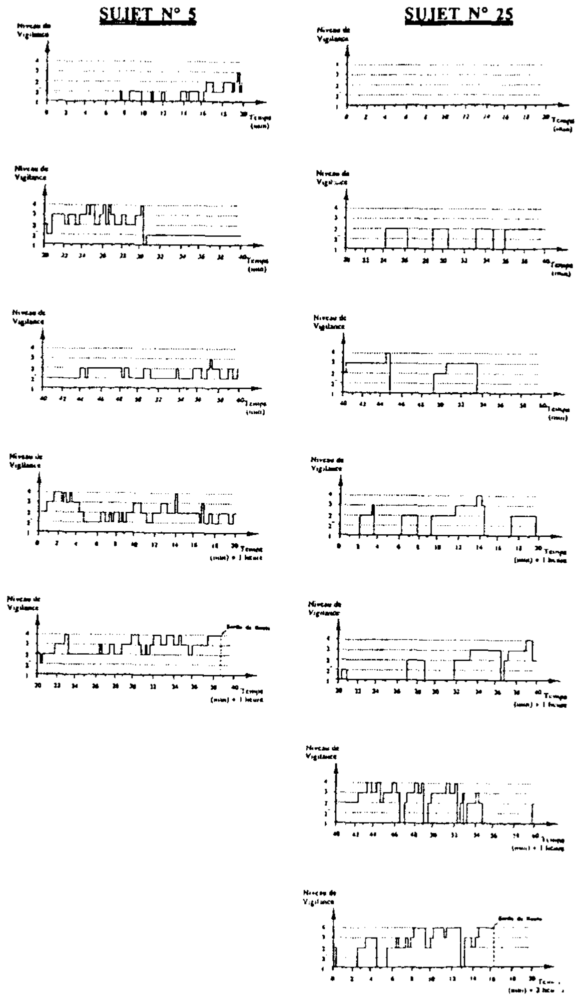

Figure 4 : Classifications physiologiques des sujets n ° 5 et 25 - Cinq niveaux de vigilance
Les sujets sont tous les deux sortis de la route après endormissement

4 - DETECTION DE L'HYPO-VIGILANCE PAR LES SIGNAUX MECANIQUES

4-1 METHODE

Le niveau de vigilance du sujet étant connu à tout instant grâce à l'analyse précédemment décrite, la corrélation entre cette référence physiologique et le comportement du sujet vis à vis de sa tâche de conduite doit être établie. Ceci permet de substituer à l'indicateur physiologique, un indicateur mécanique du niveau de vigilance, plus facile à mettre en oeuvre dans un système embarqué.

Le signal Angle Volant a été choisi dans un souci de simplicité du capteur nécessaire à son enregistrement de coût raisonnable et d'absence de contrainte posée au conducteur pour son analyse.

Afin de mettre en évidence les différences existant entre un signal de Haute Vigilance et un signal de Basse Vigilance, les paramètres suivants sont calculés sur le signal Angle Volant :

- **Surface Totale** sous la courbe du signal Angle Volant redressé : S_{tot}
- **Comptages des passages du signal par des lignes iso-degrés**. 6 paramètres sont ainsi définis.
  N_0 correspond au nombre de passages par zéro.
  N_i correspond au nombre de passages par les lignes +/- i degrés, i variant de 0,5 degrés à 2,5 degrés par pas de 0,5 degrés.

7 variables quantitatives sont donc extraites du signal. Les calculs sont mis en oeuvre en continu sur tout l'essai, sur des fenêtres de 8 secondes décalées de 2 secondes, le signal étant au préalable centré sur chaque fenêtre.

De plus, 3 variables qualitatives sont définies :

- Une variable notée **CVIR** représentant le codage des virages et comportant 3 modalités (Modalité 1 : ligne droite ; 2 : virage à droite ou à gauche; 3 : mélange de ligne droite et de virage). Cette variable est créée grâce à une détection de franchissement de seuil sur le signal "courbure" enregistré sur le simulateur

- Une variable notée **JOIN** représentant les chevauchements entre deux zones de ligne droite et comportant 2 modalités (Modalité 1 : séquence en dehors des jointures ; modalité 2 : séquence dans une jointure). Cette variable permet d'éviter toute discontinuité dans le signal, dûe à un raccordement de deux lignes droites.

- Une variable notée **VIGI** représentant le niveau de vigilance associé à une fenêtre et provenant de la classification physiologique. Cette variable prend 7 modalités (Modalité 1 : Stade 1 de vigilance ; 2 : stade 2^- ; 3 : stade 2 ; 4 : stade 3 ; 5 : stade 4 ; 6 : absence de codage ; 7 : mélange de plusieurs stades)

Ainsi, pour chaque sujet, un tableau croisant 10 variables et n fenêtres de calcul (n dépendant de la durée de l'essai), est créé.

La procédure de traitement développée ici consiste dans un premier temps à éliminer les fenêtres en virage ou en mélange de ligne droite et de virage (sélection des fenêtres pour lesquelles **CVIR = 1**).

L'élimination des jointures entre deux lignes droites est ensuite réalisée grâce à la sélection des fenêtres vérifiant **JOIN = 1**.

Le choix des niveaux de vigilance à opposer est enfin effectué : pour une détection de l'hypo-vigilance prononcée, nous conservons les stades 1 et 3 de la classification physiologique (**VIGI = 1 ou 4**). Pour une détection de l'hypo-vigilance précoce, les stades 1 et 2 sont conservés (**VIGI = 1 ou 3**).

Le tableau de départ se trouve donc ainsi simplifié et réduit : il croise maintenant 10 variables (CVIR = 1, JOIN = 1, VIGI = (1 ou 4) ou (1 ou 3), S_{tot}, N_0, $N_{0,5}$, N_1, $N_{1,5}$, N_2, $N_{2,5}$) et un nombre de fenêtres inférieur à n.

Sur ce tableau, une méthode d'analyse discriminante basée sur la construction d'un **arbre de segmentation binaire** (segmentation non paramétrique par approche Bayésienne) est mise en oeuvre [13]. Cette méthode présente l'avantage d'être rapide et facile à interpréter. Elle est adaptée à un cas comme le notre où il s'agit d'examiner si les variables explicatives permettent de discriminer les classes définies a priori. L'arbre est construit en partant d'un sous-échantillon de la population totale (échantillon d'apprentissage fixé ici à 80 % de la population et tiré au hasard). Il consiste en une suite de règles testant la valeur d'une variable quantitative par rapport à un seuil et permettant l'affectation d'un individu à une classe. Les seuils et le cheminement dans l'arbre sont calculés de manière à optimiser la coïncidence entre classe d'affectation et classe a priori. Le pourcentage de bon classement obtenu est un indice révélateur de la qualité de la discrimination et de la capacité des variables choisies à séparer les classes a priori. L'affectation d'une nouvelle séquence issue d'un ensemble test (20 % de la population totale) est effectuée en dernier lieu : partant du sommet, elle descend l'arbre jusqu'à ce qu'elle arrive à un segment terminal. Le pourcentage de bon classement ainsi obtenu renseigne sur la robustesse de l'arbre.

4-2 RESULTATS

Nous présentons ici les résultats obtenus par cette méthode sur 3 sujets différents. Le tableau de la **Figure 5** récapitule l'ensemble des paramètres d'entrée et de sortie dans chacun des cas étudiés. Pour chaque sujet, l'analyse est mise en oeuvre dans deux cas :

- Détection des hypo-vigilances précoces (opposition des stades 1 et 2)
- Détection des hypo-vigilances prononcées (opposition des stades 1 et 3)

6 cas sont donc présentés. Pour chacun d'eux, le tableau fait apparaître :

- Le nombre total de séquences : c'est le nombre de fenêtres de 8 secondes, décalées de 2 secondes, disponibles pour l'ensemble de l'essai
- La ventilation de ces séquences sur chacun des niveaux de vigilance considérés, après élimination des virages et des jointures (CVIR = 1 et JOIN = 1)
- Le taux de reconnaissance entre classe d'affectation et classe a priori, sur l'ensemble d'apprentissage
- Le taux de reconnaissance entre classe d'affectation et classe a priori, sur l'ensemble test
- Les variables apparaissant dans l'arbre et utiles à la discrimination
- Le seuil de test de chacune de ces variables

On peut observer que les taux de reconnaissance varient entre 60,89 % et 83,24 % sur les ensembles d'apprentissage et entre 55,15 % et 83,84 % sur les ensembles test. Ces valeurs sont donc assez différentes d'un sujet à l'autre.

N° Sujet	Durée Essai	Sortie Route	Niveaux de vigilance opposés	Nombre total de Séquences	Ventilation sur chaque niveau	Reconnaissance Apprentissage (%)	Reconnaissance Test (%)	Variables Testées	Seuil
-1-	1h21	oui	1 contre 2	-2365-	1 : 378 - 2 : 218	*71,37*	*74,17*	Stot	4,89
-1-	1h21	oui	1 contre 3	-2365-	1 : 378 - 3 : 522	*78,48*	*78,91*	N0 et N2,5	0,5 et 0,5
-2-	1h12	oui	1 contre 2	-2198-	1 : 451 - 2 : 210	*80,27*	*78,75*	Stot	7,79
-2-	1h12	oui	1 contre 3	-2198-	1 : 451 - 3 : 419	*83,24*	*83,84	Stot	8,29
-3-	1h07	oui	1 contre 2	-1952-	1 : 441 - 2 : 269	*60,89*	*55,15*	Stot et N2,5	6,84 et 0,5
-3-	1h07	oui	1 contre 3	-1952-	1 : 441 - 3 : 114	*70,11*	*70,53*	Stot	6,8

Figure 5 : Tableau récapitulatif des résultats de l'analyse discriminante
réalisée sur le signal Angle Volant
(Paramètres S_{tot}, N_0, $N_{0,5}$, N_1, $N_{1,5}$, N_2, $N_{2,5}$)

La reconnaissance est toujours mieux réalisée en détection d'hypo-vigilance prononcée qu'en détection d'hypo-vigilance précoce. Ceci est un résultat attendu car les modifications observées sur le signal Angle Volant sont d'autant plus marquées que la vigilance est basse, ce qui signifie que la détection est d'autant plus complexe à réaliser que l'on souhaite mettre en évidence des phénomènes précoces. Ceci étant, l'hypo-vigilance précoce peut être correctement mise en évidence grâce aux paramètres choisis, notamment dans le cas du sujet n°2.

Parmi les 7 paramètres calculés, 3 seulement s'avèrent être utiles à la discrimination : S_{tot}, N_0 et $N_{2,5}$. Les autres comptages ne sont pas des variables discriminantes. Les arbres de segmentation obtenus sont donc extrêmement simples : ils ne testent qu'une ou deux variables. Les tests sont réalisés de la manière suivante :

- Test de S_{tot} :

Si S_{tot} < Seuil alors l'individu est affecté à la classe 1 (Haute Vigilance)

Si $S_{tot} \geq$ Seuil alors l'individu est affecté à la classe 2 ou 3 (Basse Vigilance)

- Test de N_0 :

Si N_0 > Seuil alors l'individu est affecté à la classe 1 (Haute Vigilance)

Si $N_0 \leq$ Seuil alors l'individu est affecté à la classe 2 ou 3 (Basse Vigilance)

- Test de $N_{2,5}$:

Si $N_{2,5}$ < Seuil alors l'individu est affecté à la classe 1 (Haute Vigilance)

Si $N_{2,5} \geq$ Seuil alors l'individu est affecté à la classe 2 ou 3 (Basse Vigilance)

On peut remarquer que les variables sélectionnées par l'arbre diffèrent selon les sujets et selon les niveaux de vigilance opposés. Cependant, S_{tot} s'avère être le paramètre le plus discriminant dans la plupart des cas. Ceci semble montrer que la discrimination est essentiellemnt basée sur l'amplitude du signal Angle Volant. Ce résultat est également confirmé par la présence de $N_{2,5}$ dans les variables sélectionnées. N_0 n'apparaît que dans un cas : son existence prouve que la fréquence des mouvements du volant est également apte à discriminer deux états de vigilance.

Les taux de reconnaissance obtenus prouvent que les variables sélectionnées peuvent discriminer deux états de vigilance. Le sujet n° 3 montre des résultats plus médiocres en détection précoce, ce qui laisse supposer qu'il possède une stratégie de conduite différente de celle des autres sujets.

5 - CONCLUSION

L'établissement d'une référence physiologique fournissant le niveau de vigilance du sujet constitue une étape nécessaire pour réaliser la détection de l'hypo-vigilance à partir de signaux mécaniques. Nous avons montré que cette référence pouvait être établie grâce à l'analyse simultanée du signal EEG, du signal EOG et du film vidéo permettant d'étudier le comportement du conducteur. Une méthode d'analyse discriminante par construction d'un arbre de segmentation permet ensuite, à partir de variables extraites du signal Angle Volant, d'évaluer la corrélation existant entre le domaine physiologique et le domaine mécanique. Les résultats apportés par l'analyse de données conduisent à un taux de bon classement de l'ordre de 80 % et montrent que le signal Angle Volant contient les informations nécessaires à une détection correcte de l'hypo-vigilance. Les résultats sont encourageants, mais montrent que le calcul de nouveaux paramètres sur le signal Angle Volant est nécessaire à l'obtention d'une meilleure corrélation entre indicateur physiologique et indicateur mécanique.

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GREMLINS: A DOZEN HAZARDOUS THOUGHT AND BEHAVIOR PATTERNS AS RISK FACTORS

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SUMMARY

The term "Gremlins" is known as fictitious ill-tempered spirits loved by children as comic strips and movie characters. During World War II, it was an easy and unscientific way to throw blame on Gremlins which were considered responsible for unexplainable mechanical difficulties, as if a gin caused malfunctions in the aircraft.

I equate Gremlins to a dozen psychological traits which are not always seen objectively, but are very important both in aviation practice and daily life, as insidious and hazardous effects on human behavior.

The number of Gremlins (irrational judgement patterns) may not be limited to just twelve, they are likely to be more and may facilitate accidents and incidents. These twelve factors are as follows: accident proneness, traumatophily, unconscious suicide trait, phobic and counterphobic behavior, unsatisfied positive feedback desire, resignation, ritual trap, anti-authority, invulnerability, impulsivity, macho attitude and limited spontaneity.

In fact, five hazardous thought patterns (anti-authority, invulnerability, impulsivity, macho, external control) have been suggested by ERAU (Embry Riddle Aeronautical University) researchers. I have just enriched them by adding some other well-known patterns. Perhaps it has become more interesting by equating them with Gremlins.

INTRODUCTION

It was the gremlin, that diagnosis of pilots and engineers for mechanical malfunctions, caused aircraft accidents during World War II.

"Gremlins" is a concept meaning ill-mannered gin, which was used as an accuse for unexplainable accidents due to technical insufficiencies in that era. Today they are nothing but puppets and movies characters. Reasons of accidents are explained by more scientific methods.

Although modern technology presents materials providing safety in almost all conditions, accidents continues on faults rising from human beings. This means hardware problems were solved on big scale, but still problems of software holds (11, 12, 13, 14).

In this concept, it fits more to use gremlins as "ill-temperness belonging human psychology that may cause risk". There are many risk factors related with human psychology.

The following define a dozen of psychological risk factors (gremlins) on the accident base.

1. Accident Proneness: Among the causes of accidents, virtual elements are always found to be interesting. One of them is really a gremlin that, element of accident proneness. People called as ill-omened in public, are known that they break something in and around and hurt themselves, and others. According to researchers people are responsible in 10% of accidents at the rate 75%. In the same way, 33% of all traffic accidents are caused by 4% of drivers (15).
   This might be related with personal stress cumulation, physical and intellectual accuses or by self punishing motives (4). But at the end, it seems that some people carry the accident causing manner and seeds of their disasters by themselves. It is understood that unconscious masochistic motives stand behind the accidents, which look like a bad chance (1, 2). Unfortunately, there isn't any test to diagnose these motives that no one accepts. But what possible is, to pursue the persons in long terms and work statistically in which everything, including the negligible accidents, is recorded to find out the concentration of events.

2. Traumatophily: Some people enjoy trauma, they have a tendency to traumatic life being not aware of this. Every action taken, turns into trauma by jumping into troubles having no comfort at all. The inclination of acting out may lay down beneath their behavior in order to realize what they are afraid of or to get rid of internal stresses. The aim of these traumatic manners is not to reach pleasure, but to avoid discomfort (3).

3. Unconscious Suicide Motivation: The worse case than to be found guilty for someone is to feel guilty and to think that it's necessary to be punished by himself. For instance a person feeling guilty for the death of another, may be in the guiltiness of being alive (5). Having the compensation feeling, they prepare the scenario of their death unconsciously. This is called as "The Law of Talion" meaning an eye for an eye (1). In the USA, accidents are reported each year that in the form of crashing onto church, school or a bar, ending with the death of the pilots, ending with the death of pilots, clearly informed as suicides (10). From the other side, Erica Jung indicates in her novel that, pilots performing KAMIKAZE divings experience an excitation that costs them their life, having feelings more severe than orgasm (7). If a careful comparison is made, difference between the accident proneness, traumatophily and, unconscious suicide motivation can be realized.

4. Phobic and Counter Phobic Manners: Worries and fears, as the source of all feelings of people being expressed in case of danger and objects, are natural and universal reactions (8).
Otherwise, humanely natural fears are feasible which are called to be "vise fears".
"Fearlessness of people do not indicate their fearlessness and strength but, foolishness". Anhealthful thing is "to be afraid from cases that actually do not worth" or "to try to compensate the fears by counterphobic behaviors". Some examples of attempts that people try to give a message, such that they do not show fear and can cope with risky activities are driving fast, involving a fight continually, dangerous sports or unnecessary courage, etc. For people having a gin (gremlin) in the form of insubstantial fear or excessive defenses developed against that, it is hard to work safely and to continue their lives healthfully for a long term.
The one who knows the reasons of what he is doing, is the person who can rescue himself from these vicious circles.

5. Positive Feedback Insatiability: Being motivated is a need for everybody, but while acquiring this insatiable manner is a kind of insatisfaction sign.
Vise people should have some higher level satisfactions like performing the duty properly, to produce, to create, usefulness and feelings of realization of himself than appreciation of the leader or a group. A person appears in the afford of being admired and, to be known as exceptional, may really create an impression as diligence or success, but may not realize that he enters the risky region having all the indicators striking red.

6. Resignation: Here, in spite of pain and distress, entrusting himself to God and seeking a wisdom in that take place, instead of thinking there exists something to do even in most negative cases. As though life goes on a predefined scenario and behaviors of people are controlled from outside (9). Statements like "What is fated will happen.... attempts are useless... not in one's hand.... fate..." are the forms of these ideas.
Not to interfere to events and leaving the responsibilities to supernatural forces, to expect help from false beliefs are the examples of pacifism. But resignation is a vice in the meaning after every possible thing was done and wait without panic afterwards.

7. Ritual Trap: Repetitive jobs begin to be performed automatically without care of time. The same checks repeated thousands of times and the same monotonic duties may mislead to a belief that everything will go well resulting in a manner, in which no importance is given.

Situation that, people work with the same mean, has positiveness. On the other hand, due to unification of man and machine and recognization of machine habits, negative aspect is, magical presumption of man that no hazard comes from machine since he builds a close relation and feels he is different. At the end by less regarding the rules, within excessive self confidence, will make the situation closer to stealthy danger. The fact that some professionals appreciated in various fields (driver, pilot, surgeon) drive the lifes into danger, is known.

8. Antiauthority: People against the authority cannot endure the rules and the person having the power of control on them. They show reaction to those, indicating how to do the job. They do not want to understand that, rules born from many experiences. They exaggerate the detail faults of rules as excuse. Only due to this reason, there are many people being lost in accidents, or skilled persons leaving their job due to lack of discipline. This behavior, observed on pilots, timely, looks like a reflection of invulnerability and macho figures (9).

9. Invulnerability: Examples of tales: bullets bouncing off on Superman's chest, nowhere on Akhilla injurable by arrow, except his heel, show that this way of thinking is present in people's mind more or less. Contemporary fantasia heros like the Terminator, Roger Rabbit, Hulk, Batman and James Bond armed with these features are presented and accepted. A number of persons act as they will not die as a defence is not low (6). Wrong reasoning (gremlin) as if all accidents and badnesses are for others, "The bitter eggplant does not get frost-bitten means the bells of danger are ringing. In research it was found to be the widest wrong thinking pattern among the others by 43% (9). It will be proper to explain "healthy invulnerability" by opening a parenthesis. It can be said that there is a need to invulnerability to some degree for the human being having limited life, for living out of death's shadow or to ease people engaged in really risky works, for perceiving the fearless. But ignoring the visible danger and to play Pollianniaism till the end is pathological.

10. Impulsivity: Some people have a tendency to behave spontaneously and emotionally. They have no patience to consider the possibilities and to think for choosing the best of them. The shortest expression of this act is: "Just do it!" (9). This hastiness cannot be qualified as "Reflective application of certain behaviors in certain situations" obtained by training or "decidedness, self confidence or courage". These impulsive people showing emotional and sudden behaviors followed by penitence are in a group having high accidental risk potential.
The phrase in American slang, "off the cuff", is for oral impulses. It is a fact of saying whatever comes into mind by never measuring and breaking.
There is a proverb calls attention to the similarity between driving and life styles. The same thing is also valid for behaviors in a game. Either in chess or football; people acting irregular, impulsive, coward or masochistic, probably behave in the same manner in flight and real life also.

CONCLUSION

Some certain personality variances effect the decision and judgement functions. These disorders reflected to thinking and behavior, sometimes may be leading reasons of accidents.

Effects, defined as gins in this writing, do not only cause accidents, but may be a barrier to harmonic and happy life also. Some of the features of gremlins are: becoming a beast when fed by midnight, reproducing when they contact with water and dying in daylight.

Under the light of these knowledges what can be recommended is: "Everybody should find their gremlins, terminate them by exposing day light and should not feed in order not to let them reproduce and become beasts".

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EFFECTIVENESS OF BIRTHDATE BIORHYTHM THEORY ON FLIGHT ACCIDENTS

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SUMMARY

Birthdate Biorhythm Theory presents a daily guide line to people about the time of their highest and lowest performance. The theory is that it is possible to estimate in which days physical, intellectual or emotional success or failure would happen.

Many research results show no significant relationship between the theory and actual events. But sometimes the theory has an artificial (placebo) effects on some people if they are concerned about it. Some curious pilots may calculate their critical days and this state of mind may make them really accident-prone.

We have charted biorhythm graphics of 200 Turkish Air Force pilots who were involved in aircraft accidents, 75 of them have died and remaining 125 pilots survived. The existence rates of critical dates and accident days have been compared statistically and results were discussed in this investigation.

It is known that rhythmic motions of the moon, the sun, stars and especially the earth in infallible order, continuing for millions of years effect the living beings.

Periodical physical alterations like night-day time, summer-winter and tidal motions have fomed the biological rhythms by being ornamented to memories of living beings. An example of biological rhythm from the world of people that goes with the physical rhythm in synchronization with nature can be given as full-moon days. It is known that during these days tides in the erotical and romantical emotions occur and those people are said to be lunatic, loony or moon struck.

Some people have the internal clock adjusted to sleep and get up early (like a lark), and the others have it adjusted to sleep and wake up late (like an owl). Even it can be realized that sleeping, eating and toilet requirements have biological rhythms. In the world of animals the behaviors like hibernation, migration, copulation etc. are observed to be in periods. To explain such rhythmical behaviors, scientists have done some studies on plants, animals and volunteer people. The most important stimulator (zeitgeber) that starts the daily rhythms of human beings is the light. People being light-active and diurnal, receive the light through his eyes that increases secretion of the melatonin and reduces the serotonin by following the way through the retina, optical nerve, visual cortex, hypothalamus and hypophysis. Then the operation of system accelerates by increasing thyroid, surrenal and sexual hormone secretion. All these events occur at the awakening phase of people by daylight. On contrary to sleeping period, in which number of breathe, heart beat, metabolism and blood pressure reduces, in wakefulness body temperature increases, digestive system and kidneys and increase rate of cells becomes faster (7,8,9).

It is being seen that internal physiological sessions in the form of symphony having a magnificent periodical downings and risings (4). There exists a rhythm, belong to the life of living things known on the earth. This is one of the rules of the universe (7).

There are three main rhythms: Infradian (has a duration longer than a day for example seasonal, diseases, anniversary phenomenon, menstruation period, etc.) Supradian (short term rhythms occurring along the day such as EEG, EGG, REM, breathing, gastric secretion, etc.), Circadian (24 hourly rhythms, like hormone secretion during sleep-wakefulness period, changes in level of electrolytes, increase and decrease in cell wall permeability).

Circadian rhythms, since they cause the decrease of the once to work in shift that requires the change of sleep-wakefulness sessions, was notices in industrial accidents. In aviation, while flying transcontinental - transmeridian, if the differences between the internal clock and the local time of destination, in accordance portrait that called jet lag occurs due to dysynchronisation. This is more severe in flights from west to east and is important for business men, scientists, artists and sportsmen as well as pilots (2,7).

As it is seen, the scientific studies on the subject continues, that it was not accomplished to be explained yet properly with its reasons and mechanism. This tentative gap in science is being tried to be filled by the popular science or pseudoscience, as it is the case in other fields. In the manner that exploiting the wonders of ordinary people, interesting articles take place in the press and even books are written.

"Popular Birthdate Biorhythm Theory" presents a daily guidance to people for reaching highest potential with a simple calculation method, on which day the physical, the emotional and the intellectual activities become well or bad. These calculations can be performed within 5-10 min. manually and 5-10 sec. if through by use of computer (10).

According to the theory, there are three phases in every person's life. Physical Term continues 23 days, Emotional Term longs 28 days, and Intellectual Term lasts 33 days. Each three phase, zero being at the birthdate, continues during life by drawing sinusoidal curve, having firstly positive then negative regions. The points formed by intersection of curves and the abscissa are considered to be critical days on which related function decreases and accepted as every kind of negative cases may occur (5,10).

MATERIAL AND METHOD

200 pilots from Turkish Armed Forces included in the investigation who had accidents between the years 1974-1987. 75 of 200 have died during mishap, while the rest injured or not affected luckily. Distribution of the 75 death, 2 from the Navy, 5 from the Army and 68 from the Air Force.

Inspection was carried out on computer with the use of graphics obtained by the programme, to detect the period and if exists, critical days corresponding the mishap day.

Statistical consideration handled by Pearson Chi Square Test.

FINDINGS

TABLE - I
TABLE - II
TABLE - III
TABLE - IV
TABLE - V

DISCUSSION

In 1979 panel and conferences of AGARD were concentrated on the subject biorhythm, and the number of researches enough to fill a book were printed (5,6,9,). Conclusions of these researches show contraversion with the suggests of the theory. Symptoms obtained in investigation carried out by us also, do not support it.

1. A reasonable relation between the accidents coinciding with physically, emotionally and intellectually critical days and accident not coinciding couldn't be found according to Chi Square Test (Table-I).

2. It was examined if being on positive or negative stages of these 3 periods had effect on the mishap occurred, and no considerable reason was found.

3. In Table-V by thinking the possibility that critical day suspend a day before or later, all the accidents within this period (∓ 1) were shown. On the same table the possibility of relation between the critical days and official reasons having no meaningful results at the end was shown also. There should be two reasons for the numbers at the upper left corner of table being such high. Firstly, since the flight is performed by pilot and aircraft, piloting and material factors show higher level naturally. Secondly, since physical period is the shortest period (23 days), it is the most repeating and most possible term for crossing mishap day mathematically. Therefore, to consider as accidents occur mostly on physically critical days, can be misleading.

On the other hand, even though the existence of such rhythms possible, the theory disregards the rhythm shift probability rising from personal, psychological, physical traumas, stresses and diseases. Since it will not be possible to determine the rhythm shifts, all the calculations collapse. So it shouldn't be expected to believe a mathematical formulation determent on unknown criterions, like believing in a mystic taboo.

RESULT

The result reached by this investigation in short way is that, popular birthdate biorhythm theory is not capable of explaining the aircraft accidents. Actually this matter is not considered in classics of aerospace medicine but circadian rhythms (1,2,3,7). It may not be claimed that, a confident flight can be performed even hundreds of systems consisting aircraft, work in harmony. Because many people of which the most important being the pilot have more indefinite physiological and psychological systems. Even in ideal conditions that all these go well, an accident may take place due to other environmental reasons. In those cases, it may lead to miss the objective factors to try to find factors causes in magical formulation.

Ideal minimum level can be reached by objective and captious inspections in order to decrease the accidents. The most important conditions in this is to consider the reasons and precautions from scientific perspective. It may be interesting to approach by simple method requiring scientific discussion but one must not fall in its traps.

Especially for young pilots it might turn to stresses inviting the accident tried to be avoided, that due to decrease in concentration and creation of unnecessary anxieties by facing with popular birthdate biorhythm theory in actuality occasionally. This investigation was made for clearing the situation.

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TABLE I - COMPARISON OF MISHAP RATES ON CRITICAL DAYS WITH NON-CRITICAL DAYS

	CRITICAL DAYS			OTHER DAYS	TOTAL
	PHYSICAL P	EMOTIONAL S	INTELLECTUAL C		
FATAL ACCIDENTS D (+)	12	3	9	51	75
INFATAL ACCIDENTS D (-)	18	9	11	87	125

(X^2=2,15, SD=3, P>0,05)

TABLE II - COMPARISON OF FATAL AND INFATAL OCCURANCES OR MISHAPS ON THE DAYS WHEN THE PHYSICAL PERIOD (-) & (+)

	(-) PHYSICAL PERIOD		(+) PHYSICAL PERIOD		TOTAL
	EXISTENCE	INEXISTENCE	EXISTENCE	INEXISTENCE	
FATAL ACCIDENTS D (+)	34	41	29	46	75
INFATAL ACCIDENTS D (-)	47	78	60	65	125

(X_1^2=0,86 P>0,05 X^2=1,3 P>0,05)

TABLE III - COMPARISON OF FATAL AND INFATAL OCCURANCES OF MISHAPS ON THE DAYS WHEN THE EMOTIONAL PERIOD (-) & (+)

	(-) EMOTIONAL PERIOD		(+) EMOTIONAL PERIOD		TOTAL
	EXISTENCE	INEXISTENCE	EXISTENCE	INEXISTENCE	
FATAL ACCIDENT D (+)	34	41	38	37	75
INFATAL ACCIDENT D (-)	61	64	55	70	125

(X_1^2=0,11 P>0,05 X_1^2=0,59 P>0,05)

TABLE IV - COMPARISON OF FATAL AND INFATAL OCCURANCES OR MISHAPS ON THE DAYS WHEN THE INTELLECTUAL PERIOD (-) & (+)

	(-) INTELLECTUAL PERIOD		(+) INTELLECTUAL PERIOD		TOTAL
	EXISTENCE	INEXISTENCE	EXISTENCE	INEXISTENCE	
FATAL ACCIDENT D (+)	34	41	33	42	75
INFATAL ACCIDENT D (-)	46	79	68	57	125

(X_1^2=1,09 P>0,05 X_1^2=1,63 P>0,05)

TABLE V - COMPARISON WITH ACCIDENT REASONS & CRITICAL DAYS

		CRITICAL DAYS							TOTAL
		± 1P	S	C	PS	PC	SC	PSC	
REASONS	PILOTING (>50%)	25	15	20	1	5	–	–	66
	MATERIAL	14	9	11	1	2	–	–	37
	ADMINISTRATIVE	3	1	3	–	–	–	–	7
	MAINTENANCE	2	1	2	–	–	–	–	5
	UNKNOWN	2	–	–	–	–	–	–	2
	OTHERS	–	–	2	–	–	–	–	2
	TOTAL	46	26	38	2	7	–	–	119

($X^2=0,55$ $P > 0,05$ $X^2=0,58$ $P > 0,05$)

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14. Abstract

These proceedings include the Technical Evaluation Report and 58 papers of the Symposium sponsored by the AGARD Aerospace Medical Panel held at the Altin Yunus Hotel, Cesme, Turkey, April 27th—1st May 1992.

Since the commencement of aviation, accidents have occurred for a variety of reasons in both fixed- and rotary-wing aircraft. As the complexity of aviation systems increased, so did the task of investigating aircraft accidents. At the same time, advanced techniques in aviation and weapon systems have exacerbated greatly the physiological and cognitive demands on aircrews. The result is that aircraft accidents due to material causes have diminished progressively while the percentage of human factor-caused accidents has not. New technologies have had to be applied in order to determine the cause of accidents and new techniques developed to assess the mechanisms of injuries sustained in accidents. The purpose of the Symposium was to consider the recent trends in aerospace medical investigative techniques in human factors-related accident reconstruction.

The papers address a variety of topics including: (a) human factor causes of accidents; (b) occupant injury investigation; (c) test devices for dynamic response; (d) fixed- and rotary-wing aircraft accident data; (e) spatial disorientation; (f) injury and accident prevention; (g) post crash fire, toxicology, and forensic pathology; (h) crew error prevention and (i) crew risk factors.

These proceedings will be of interest to those involved in the investigation of aircraft accidents, their causes and the prevention thereof.

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